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Season of Seeding, Mowing and Seed Mix Richness for Native Plant Community Development in the Aspen Parkland

by

Christine Lori Pitchford ©

A thesis submitted to the Faculty of Graduate Studies and Research in partial fulfillment of the requirements for the degree of Master of Science

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Land Reclamation and Remediation

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ABSTRACT

Twenty grasses and forbs native to the Aspen Parkland were fall and spring seeded at two Alberta sites in four mixes of differing species richness. Generally density, percent biovolume and density-biovolume of seeded grasses and forbs were higher, and that of non-seeded species lower, in spring than fall seeded treatments. Ground and canopy cover were not affected by seeding season. Mowing increased seeded plant density, biovolume and density-biovolume during the first growing season but not the second. Mowing decreased non-seeded species biovolume during the first and density early in the second growing season. Mowing decreased bare ground in the first and early in the second growing seasons. Seed mix species richness had no effect on plant community species richness; it also had no effect on six grasses common to the mixes, non-seeded species or ground and canopy cover.

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CHAPTER I. INTRODUCTION

1.0. THEORIES OF PLANT COMMUNITY DEVELOPMENT

Regardless of the form of revegetation, expectations of the resulting plant community are based on theories of biotic and abiotic interactions that affect plant community development (Pyke and Archer 1991). Revegetation research has been dominated by studies that provide some information about what works under specific conditions, but tell us little about the underlying ecological processes (Call and Roundy 1991). At present, our understanding of mechanisms regulating ecosystem processes is limited; this lack of knowledge is confounded by the constant debate in literature as to what forces drive succession and the importance of competition and diversity in determining community composition. As a result, the applicability of general ecological theories has been questioned. Nevertheless, it is essential to identify and understand these factors affecting the development of plant communities to achieve successful revegetation.

1.1. Disturbance

Grime (1977) defined disturbance as the "partial or total destruction of plant biomass" due to grazing, plowing, mowing, trampling, disease, fire, soil erosion and other natural processes. Often, disturbance signals the beginning of plant community development. In reclamation, disturbance may be the construction of a pipeline or wellsite, the cultivation of land for agriculture or the construction of roads and facilities in a national park. The size, intensity and frequency of disturbance may vary considerably and play a major role in plant community development and organization (Bazzaz 1983). The resulting plant community may be composed of seeded species, contributions from the seedbank, invasions from off site or any combination of the aforementioned.

1.2. Invasion

Plant communities rarely begin as complex systems, nor do they remain static over time (Robinson and Dickerson 1987). Communities are assembled by sequences of invasion (Robinson and Dickerson 1987). For invasion to be successful, the species must be near enough for colonization to occur and sufficiently adapted to survive the environmental conditions. The question then arises whether the outcome of colonization of a given group of species will always be the same.

The facilitative theory of succession proposed by Clements (1916), wherein a species modifies the environment and therefore makes it suitable for another species to invade, would suggest a consistent outcome of colonization. However, a more recent study by Connell and Slatyer (1977) illustrated that early colonists are able to preempt a limiting resource and prevent later arrivals from becoming established. Robinson and Dickerson (1987) subjected identical areas to the same rate but different sequence of species invasions and found very different communities resulted. Instead of early arrival, Robinson and Dickerson (1987) stressed the importance of arrival when resource levels are suitable. Despite their differing emphases, these results indicate that arrival sequence is influential in determining community structure.

Tilman (1997) found the total cover of pre-existing species was independent of the number of species added as seed, suggesting that invasive species filled previously empty sites. Whether or not a species invades at all is another issue, and ~~is~~ often dependent on the competitive ability of species already occupying the site (Burke and Grime 1996, Tilman 1997). Species richness is hypothesized to influence invasibility because plants in species rich sites are assumed to have more efficient use of limiting resources, and thus be more competitive to potential invaders (Robinson et al. 1995).

1.3. Competition

Competitive interactions occur during community development and can lead to differences in community structure (Drake 1991). Variation in the intensity of competition controls species diversity and composition of plant communities (Grime 1973, Connell 1978, Huston 1979). Most theories of development focus on competition as the critical factor determining the species composition of a community.

Wherever plants grow, regardless of species composition, differences may be observed in growth, production and survivability. However, not all of these differences may be attributed to competition. In an effort to clarify, Grime (1977) defined competition as "the tendency of neighboring plants to utilize the same quantum of light, ion of a mineral nutrient, molecule of water or volume of space". Competition may occur directly, through allelopathy, or indirectly through competition for resources. Furthermore, Bonsall and Hassell (1997) considered direct competition rather insignificant compared to the equal or greater importance of indirect competition in community development.

Within the topic of indirect competition, intense debate continues over whether diversity is affected by competition related to nutrient supply. According to Connell (1978) and Drake (1991), competition intensity increases with nutrient availability, resulting in decreased community diversity. Thus, by increasing plant growth, high nutrient supplies also increase competitive interactions, leading to decreased community diversity. This hypothesis is supported by the studies of Levins (1968) and Vandermeer (1970) that indicate intense competition results in low diversity among competitive species.

Grime (1973) also found competition the causal factor in maintaining low species diversity. Grime proposed a bell shaped model, where the lower end represents low environmental stress and the higher end, extreme environmental stress. At the low end, resources are abundant and competition maintains low species diversity. On these infertile soils, competition is less intense due to the reduced stature and slow growth rate of plants. Under extreme stress, species diversity is limited by the species' ability to tolerate limiting conditions. Therefore, maximum species diversity occurs mid-range, where competitive species decline in vigour and less dominant species are able to survive. Although competition often culminates in the above ground struggle for space and light, Grime suggested the outcome may be strongly influenced by earlier competition below ground. Variations in competitive ability may occur because environmental conditions affect the extent to which the competitive potential of a species may be realized. Fundamentally, the nature of competition varies with site conditions and it is therefore possible for a species to be a strong competitor at one site but a weak competitor at another.

However, others such as Tilman (1985), argue that competition should also be intense on infertile soils because soil nutrients would be more limiting than in fertile soil. Tilman claims that while competition for light should increase with nutrient availability, competition for belowground resources should be greatest in nutrient-poor environments. Thus, a key point of disagreement between Tilman and Grime is whether the intensity of competition is constrained by low nutrient supply. However, as Reader (1990) indicated, a major fault exists in the experiments of both Tilman and Grime. The potential effect of nutrient supply on competition was not separated from the direct effect of nutrient supply on plant performance, thus making it difficult to interpret results. Upon repeating the experiment and correcting the error made by Tilman and Grime, Reader found that low nutrient supply limited competition, thereby confirming the results of Grime.

Levels of available nutrients may also affect the ability of some species to resist invasion. Wedin and Tilman (1990) found high rates of available nitrogen in soils reduced the competitive ability of little bluestem (*Schizachyrium scoparium* (Michx.)) and big bluestem (*Andropogon gerardi* Vitman.) against weed invasion. Similarly, Clark (1998) found weed production was higher on nutrient-rich soil.

In general, the main issue in competition literature is whether the diversity of the community is affected by soil nutrient status. Whether or not diversity itself is of any significance to plant community development is another important issue.

1.4. Biodiversity

Biodiversity is a function of species richness (the number of species) and the relative abundance of species (Begon et al. 1986). At the heart of the biodiversity debate is the issue of whether or not biodiversity contributes to ecosystem stability. Understandably, there is a desire to see the claim realized as a potential means of protecting and restoring damaged ecosystems.

Elton (1958) was the first to suggest that biodiversity begets ecological stability, citing as evidence the greater frequency of pest outbreaks in croplands versus complex grasslands. Stability is the tendency for population perturbations to dampen, thus returning the system to a consistent state (May 1974). Hutchinson (1959) claimed the greater the number of links in a system, the greater the chance of damping oscillations. However, May (1974) presented mathematical evidence that diverse ecosystems are in fact less stable than simple systems. May's model showed that diverse ecosystems had more complex webs of interaction among species and, therefore, larger repercussions of disturbance among species. The main point of this and other mathematical models of biodiversity is the greater the size and connectedness of the system, the larger number of oscillation modes it possesses, thereby increasing the chance of instability. Despite these findings, the debate continues in current literature.

Several recent studies support the diversity-stability hypothesis that ecosystem functioning is sensitive to biodiversity (Frank and McNaughton 1991, Tilman and Downing 1994, Naeem and Li 1997, Tilman et al. 1997). According to Tilman et al. (1997), diverse ecosystems tend to be more stable; however, populations within them may have great variability. Still, the assumption that "biodiversity begets a stable ecosystem" is not shared by all.

Leps (1982) suggested that ecosystem processes were determined by the functional characteristics of the species, rather than their number. Grime (1997) reported that it is the biological characteristics of the dominant plants, rather than their number, which controls ecosystem processes. This is referred to as the species-redundancy hypothesis (Walker 1992), which asserts that many species are similar and that ecosystem functioning is independent of diversity, assuming major functional groups are present.

Solbrig (1993) defined a functional group as a group of species with similar characteristics, behaving in a similar manner. These groups are arbitrarily chosen, and may include legumes, C_3 and C_4 plants, woody plants and forbs (Tilman et al. 1997). McNaughton (1977) theorized that the more functionally similar species present, the greater the community's resilience to environmental change. In fact, Tilman et al. (1997) found that ecosystem function is more dependent on the diversity of functional groups than the species number. However, Chapin et al. (1997) found that both function and species richness are important influences on ecosystem process.

Although it is recognized that the species composition and biodiversity of a community changes over time, there are numerous theories that propose means and mechanisms. Tilman (1985) suggested that abundance patterns would vary with resource availability, while MacArthur and Wilson (1967) suggested abundance patterns change through succession. The continued debate in the literature indicates that no model of biodiversity has achieved universal acceptance and applicability. A comparison of popular models reveals tradeoffs among the strengths of various models. As the preceding discussion of successional models indicates, the prolific abundance of theories and models has lead not to acceptance, but to further examination and scrutiny of existing models.

1.5. Succession

The concept of succession provides a theoretical basis for revegetation. The process of succession determines the rate and nature of revegetation and influences plant community development (Redente and DePuit 1988). According to Redente and DePuit (1988), we best understand the initial process of succession (ie. migration and ecesis). However, our understanding of subsequent processes of competition, reaction and stabilization, is lacking.

Classical theory portrays succession as a sequence of species replacements driven by autogenic processes. Autogenic succession results from changes in the physical environment caused by the community (Odum 1969). Clements (1916) defined succession as the facilitative process of one species preparing the way for the next. Although his theory is insightful, it oversimplifies the phenomenon of succession with the concept of single equilibrium communities and a deterministic successional pathway. Westoby et al. (1989) proposed that community dynamics could be more accurately described as a set of discrete states and transitions between states, rather than as steady vegetation change along a single continuum.

Odum (1969) described succession as a series of changes in biomass and primary productivity, leading to maximum productivity and biodiversity at the climax stage. Central to Odum's theory is the pattern of increasing species diversity as communities approach climax. However, recent studies (Peet and Christensen 1980) suggest that maximums in biomass and productivity tend to occur at the central period of successional sequences, rather than at climax, as predicted by classical theory. Following this realization, several modern theories of succession have evolved.

Modern theories of succession point to physical stresses on plants and resource competition among plants as the main mechanisms of succession. Drury and Nisbet (1973) argued that succession is simply a type of stress gradient to which plants are adapted. According to them, the cause of succession is the correlation among stress tolerance, rapid growth, small size, short life and wide dispersal of seed. The main feature of the suite of life history characteristics is the tendency toward an inverse relationship between features that confer early successional success and those that confer success in the later stages of succession. Pickett (1976) also viewed succession as a gradient of competition, central to which are life history and physiological characteristics. However, Pickett's view focused on interactions of vegetation strategies without reference to climax as the stable state of succession.

Egler (1976) argued that succession, specifically secondary succession, is a consequence of differential longevity. More specifically, dominant vegetation enters a community in the earliest stages of development when competitive pressures are low. Drury and Nisbet (1973) considered species composition a critical determinant in community development, implying that the failure of a species to establish early reduces or eliminates its chances of subsequent dominance. This modern theory of inhibition contrasts Clements' traditional theory of facilitation.

Horn (1975) presented the model of succession as a stochastic process based on Markovian models. The result of this model is convergence to a steady state, regardless of initial conditions. The common feature of the modern models of succession is the emphasis on life history, rather than the properties of the community as a whole which were emphasized by traditional theory.

Huston and Smith (1987) proposed a model of succession that is also based on individuals, rather than populations. In this model, the competitive ability of each individual is based on a set of life history characteristics within the individual's environment, rather than population parameters. Huston and Smith's model is a mix of modern and classical theory and is based on nonequilibrium dynamics of competition and Odum's belief that succession is autogenic.

A recently proposed population model of succession is Tilman's resource-ratio hypothesis (1985). The critical assumption of this model is that competing species experience trade-offs in their resource requirements, such that the superior competitor for one resource is an inferior competitor for another. Tilman's theory also assumes that the competing species reach a competitive equilibrium along a changing light-nutrient gradient. Essential to this assumption is that the rate of change in resource availabilities is slow, relative to the rate of competitive displacement. The major criticism of this model is that it aggregates many components of competitive ability into a single parameter which cannot respond to changing conditions with the same dynamics as several individual parameters. Huston and Smith (1987) claimed population models inadequately describe succession because they "aggregate individual plants with different growth rates, reproductive capacities and mortality probabilities into a single population".

Despite the abundance of recent studies, there is no dominant theory of succession or explanation of mechanisms that affect it. Traditional theory (Clements 1916, Odum 1969) has provided broad insights into the intricacies of succession, however, because general theory does not explicitly include environmental variables (Tilman 1990) succession cannot be predicted. Perhaps the search for an all-encompassing theory of succession is in vain. Although similar processes occur in different environments, the processes may not occur for the same reason, or for the reason we believe. Perhaps, as Huston and Smith (1987) indicated, several factors cannot be aggregated together into a general theory. However, Tilman (1990) argues models that do not include specific interactions cannot make predictions of the outcome of a plant community. Further study and debate is required to determine whether individual parameter models are more apt to predict and explain succession than aggregated or population models.

2.0. FACTORS AFFECTING PLANT COMMUNITY DEVELOPMENT

Despite the numerous theories of plant community development and the increasing demand to use native species in reclamation, information on factors affecting development is lacking. "The requirements for successful establishment of native grasses are little known at present" (Hagon and Groves 1977). Native species tend to be used in reclamation with the assumption that they will respond to management practices in a manner similar to introduced species. However, little research has been conducted to determine the reality of such an assumption. Further research is required to determine basic information regarding season of seeding and seed mix composition. These and other factors which are believed to affect native plant community development can be divided into those which are influenced by site characteristics and those which are influenced by management.

2.1. Site Characteristic Influences

2.1.1. Seedbank

The seedbank is composed of seeds, buried or on the soil surface, which can survive long periods and germinate when the habitat is disturbed (Roberts 1981). There are two likely mechanisms through which seeds become buried in soil. Small seeds are more likely than larger ones to be washed into small fissures in the soil surface and buried by activities of soil microbia (Mortimer 1974). Burial of large seeds likely occurs due to activities such as plowing which disturbs the soil.

Cultivation of agricultural soils usually results in the appearance of a large number of annual weed seedlings. Emergence of weed species is influenced by biological, physical and environmental factors, such as seed dormancy (Baskin and Baskin 1985), moisture and temperature (Weaver et al. 1988), light, soil fertility and frequency of soil disturbance (Roberts 1981). Furthermore, the location of seeds within the soil profile can influence seed germination and seedling emergence (Buhler and Mester 1991).

The role and functional significance of the seedbank in plant community development is not well documented (Hayashi and Numata 1971). It is recognized that seedbanks provide a reserve of dormant individuals that replenish the vegetation when losses of mature vegetation occur (Baskin and Baskin 1978). However, seedbanks may also be important in maintaining floristic diversity by enhancing genetic diversity (Baskin and Baskin 1978).

Current literature describes germination and seedling responses under controlled laboratory conditions that are not representative of the stochastic environmental conditions found in the field (Call and Roundy 1991). Conversely, field studies fail to measure critical environmental factors in adequate detail to assess how seedlings respond to conditions (Mayer 1986). Thus, the role the seedbank plays in plant community development remains, to some degree, unexplained.

2.1.2. Available soil nutrients

Much of the literature regarding nutrients and native species focuses on the effect of fertilization. Comparatively less research has been dedicated to naturally occurring levels of soil nutrients and the effect these nutrients have on plant community development. Fowler (1982) found species grown in soil environments with differing amounts of available nutrients had significant differences in yield. Chapin (1980) found nutrient limitation decreased root growth, photosynthesis and respiration. Willms and Jefferson (1993) found species composition in the mixed prairie was most affected by available water during the growing season and by soil nutrients, especially nitrogen. Parrish and Bazazz (1982) and McLendon and Redente (1992) also found that nitrogen availability influenced species composition in a number of disturbed ecosystems. According to Belnap and Sharpe (1993), limitation of nitrogen availability favors later seral, perennial plants, while increased nitrogen availability favors early seral annual plants. There is little mention in the literature of the effect of phosphorus, potassium and sulphur on plant community development.

2.1.3. Climate

The influence of climate encompasses several factors including temperature, precipitation and soil moisture. Climatic factors, primarily low and erratic precipitation and temperature extremes, exert an overriding effect on the success or failure of a revegetation project. Soil water content and soil temperature also have significant effects on seed germination and seedling establishment (Holt et al. 1994). The seeding date can be selected to coincide with suitable soil water content and favorable temperatures. Therefore, the influence of climate on the establishment of native vegetation is often linked to the season of seeding (Hagon and Groves 1977).

Most research on the effect of precipitation and soil moisture on plant emergence and establishment has been conducted in the arid rangelands of the United States. Under these conditions, the greatest factor determining successful emergence was available soil moisture (Hull 1948). Although the Aspen Parkland Ecoregion is a mesic region, soil moisture may still be significant to emergence and establishment.

Hagon and Groves (1977) found *Stipa* grasses less sensitive to temperature than other species, indicating emergence sensitivity to temperature is species specific. They also found emergence and seedling growth occur in temperatures ranging from 5 °C to greater than 20 °C; however, each species had a specific temperature range for optimum growth. Romo et al. (1991) found germination of rough fescue (*Festuca hallii* (Vasey) Harms)) was highest at temperatures of 15 to 20 °C, although seeds germinated over a wide range of temperatures.

2.2. Management Influences

2.2.1. Species selection

Species selection should consider the basic characteristics and life history attributes of species, as well as, site characteristics, end land use and seed availability. Beyond this, there is considerable debate as to how species should be selected and mixes developed. The greatest debate focuses on whether species composition should be based on percent weight or percent pure live seed. There has not been a study conducted to test the advantages of either method; the decision is usually based on personal preference.

In his studies of plant community development, Tilman (1985, 1997) constructed seed mixes based on percent weight of each species. This is also the method commonly used in the reclamation industry. The disadvantage of this simple method is that a mix constructed with equal weights of each species will be composed of few seeds of large species and numerous seeds of small species. Theoretically, this could significantly affect the resulting plant community by creating an abundance of, and potentially favoring, small seeded species. The counter argument is small seeds have lower carbohydrate reserves than larger seeds and are therefore more vulnerable to desiccation. Accordingly, it may be justified to increase the amount of small seeds to achieve a balanced end community.

The other approach to designing a seed mix is to include equal amounts of pure live seed of each species (pure live seed is a measure of the purity and germination percentage of the seed). The basic premise of this approach is to design a vegetation community with an equal number of plants of each species; thereby preventing competitive advantage based on numerical abundance.

It may be argued that the number of plants is no more or less important than the basal area or percent cover of each species. However, the decision to base seed mix design on an equal number of pure live seeds reflects the assumption that the end community will have an equal number of plants per species. Admittedly, this assumption ignores differences in seed storage capacities, which may play a role in determining the rate of germination and establishment. Nevertheless, the main goal of this decision is to create a theoretically equal starting point for community development; a starting point that does not numerically favor one species over another. It is assumed that this equal starting point will facilitate analysis of the resulting plant community.

Recently, biodiversity studies have been debated because of species selection. Huston (1997) and Grime (1997) pointed out that several of the apparent benefits of biodiversity can be explained as the consequence of species selection. This is due to the more diverse communities used in experiments containing larger and more productive plant species, which were omitted from less diverse communities. This omission gave the false impression that the more diverse communities were more productive and perhaps more stable. Such an error could have been prevented simply by ensuring species present in the low diversity mix are among those included in the high diversity mix.

Another dilemma facing the biodiversity debate is the lack of research linking seed mix diversity to resulting plant community diversity. If the number of pure live seeds is equal amongst species, this argument could be reworded as the connection between species richness in the seed mix and species richness in the resulting plant community. Thus, research is needed to investigate whether a simple seed mix is capable of creating the same level of species richness in a community as a more rich seed mix. Furthermore, a question that remains unanswered is whether a species rich seed mix always creates a rich plant community or if success is hampered by competition and other processes of plant community development. Learning how to create a diverse plant community, whether through using a species rich seed mix or by encouraging invasion in a simple community, is a critical step towards studying and appreciating the issue of biodiversity.

2.2.2. Life history strategy

The life history strategy of a plant encompasses its physiological and ecological characteristics. Because these characteristics are unique to each species, it is necessary to examine the life history strategy of each seeded species to understand the role each species plays in plant community development.

Seeds contain a suite of adaptations to the local environment (Kerr et al. 1993) which explains why seeds grow in one environment but not in another. These adaptations are also the main issue in the debate over what is truly a native species. There is no official definition of native, thus it is only possible to explore the merits of the many possible definitions.

Most definitions of native vegetation place a distance restriction from where the seed was collected, which is the area within which the seeds are assumed to be suitably adapted for the local environment (Cooper 1957). Beyond this general agreement, the distance restrictions of the proposed definitions vary from a few meters (Linhart 1995) to hundreds of kilometers (Cooper 1957). While the purist approach of limiting the definition of native to a few meters is ecologically sensitive (Knapp and Rice 1994), it is unrealistic for many revegetation projects. However, other definitions tend to classify native according to provincial boundaries (Gerling et al. 1996). This definition, despite its merit of simplicity, fails to recognize that ecological similarities are more likely to occur in a west-east manner, rather than the north-south boundaries we arbitrarily define as provinces. To date, there is universally accepted definition for native species.

There is abundant life history information on community dominant native grasses; however, there is significantly less information on subdominant grasses. There is little or no information on the life history strategies of native forbs.

2.2.3. Seeding techniques

2.2.3.1. Seeding method

Seeding method affects germination and establishment (Vallentine 1989). Selecting a suitable seeding method is also essential to ensure adequate soil-seed contact. This is particularly important for small seeded species, as inadequate soil contact may lead to seedling death because the roots may not absorb sufficient water (Vallentine 1989).

There are numerous studies that document the advantage of one seeding method over another. Douglas et al. (1960) found more intensive land preparation, such as plowing and disking, reduced the competing annual weed species and allowed for greater development of the planted species. However, results are often related to specific site conditions, particularly climate, because soil moisture is often the limiting factor for machinery accessing the site. The two common methods used in Alberta for seeding native vegetation are broadcasting and drilling.

Broadcast seeding uses machinery or hand-broadcasters to drop seeds on the ground. Broadcasting may or may not be followed by harrowing or packing, largely depending on site accessibility and personal preference. Broadcasting is preferred for small grass seeds and most forbs because drill seeding places seeds at too great a depth to ensure survival (Vallentine 1989). Broadcasting is useful when moist site conditions prohibit heavy machinery access. Broadcasting also allows for random placement of seeds, creating a more natural appearance compared to seeded rows.

Despite the apparent advantages, there are several disadvantages to broadcasting (Vallentine 1989). Because seeds are left near the surface, there is a greater potential for desiccation or loss to seed eating animals (gramnivores). Seeds on the surface may be carried away by wind or water erosion, especially during spring snow melt. To account for potential seed loss, the seeding rate must be increased when broadcasting. This can significantly increase the cost of a project.

Drill seeding creates a hole in the soil and places the seed in the hole. This ensures seed placement at a predetermined depth and good soil-seed contact (Vallentine 1989). By placing the seed in the ground, there is less chance of loss to erosion or predators. However, drill seeding places seeds in rows, which is unnatural and may lead to erosion problems. Fuzzy or awned seeds may also become lodged in the seed drill.

2.2.3.2. Seeding depth

There is debate in the literature on the suitable seeding depth for native species. The ability of grass seedlings to emerge from a given depth, and establish successfully, depends in part on seed morphology (Redmann and Qi 1992). One recommendation is to place seeds at a depth equal to five times the seed diameter; however, this method is not suitable for small seeded species. Another recommendation is to plant at a depth similar to the combined length of the coleoptile and the subcoleoptile internode (Newman and Moser 1988). Many small seeded species and certain species with specific physiological requirements (ie. lack of seed reserves for emergence) must be located on the surface for germination to occur (Young et al. 1987).

The general consensus within the reclamation industry is to drill seed at a depth of 1.3 to 2.54 cm (1/2" to 1"), and to broadcast small seeds. In general, larger seeds are able to emerge from greater depths (Plummer 1943, Maun and Lapierre 1986, Zhang and Maun 1990).

Although seeding depth recommendations have been made (Vallentine 1989), few studies have been undertaken to determine from which depths seedlings successfully emerge (Call and Roundy 1991). Furthermore, caution should be exercised when selecting depth according to published data, as some studies were conducted in the field, others under greenhouse conditions. Where the study was conducted is significant, according to Murphy and Arny (1939), as optimum depths differ between the field and greenhouse because of moisture conditions. Generally, both greenhouse and field studies indicate that emergence decreases with depth; however, greenhouse studies tended to have higher establishment rates than field studies (Murphy and Arny 1939).

Ideally, seeds should be planted at a depth sufficient to take advantage of favorable soil moisture conditions, but not so deep that seedling emergence and vigour are reduced (Fulbright et al. 1985). Soil moisture conditions generally become more favorable for germination with increased depth (Rogler 1954, Lawrence 1957, Hyder 1974). However, the consequence of seeding too deep, especially for small seeds, is usually poor germination and/or a reduction in total emergence and the rate of emergence (Plummer 1943, McGinnies 1960, Kilcher and Lawrence 1970, Fulbright et al. 1985, Maun and Lapierre 1986, Lodge and Schipp 1993, Pickering and Raju 1996). Reduction in seedling vigour may also occur as a result of seeding too deep (Mutz and Scifres 1975). Conversely, inadequate root development, injury or desiccation may result from shallow seeding (Hyder et al. 1971, Vallentine 1989).

2.2.3.3. Seeding rate

Seeding rate is the number of seeds per unit area and is based on the desired number of plants per unit area and their emergence and survivability. The difficulty ensues because information on the emergence and survivability of native species is significantly scarce. Often, we try to compensate for our lack of understanding of plant-site relationships by increasing the seeding rate (Vallentine 1989).

General recommendations for seeding rate range from 200 to 350 seeds per m^2 (Vallentine 1989). Clark (1998) found the establishment rate of several grasses was lowest at high seeding rates; however, the establishment rate increased with decreases in the seeding rate. Thus, for slender wheatgrass, green needle grass, plains rough fescue and junegrass, a lower seeding rate means better establishment.

2.2.4. Season of seeding

It is generally accepted that the best time to seed is prior to the season that receives the most dependable precipitation (Hull 1948, Cook et al. 1974, Tainton 1981, Ries et al. 1987, Vallentine 1989), normally spring. Seeding at this time generally ensures suitable soil moisture conditions for germination and seedling growth. However, most species in Alberta may also be seeded in late fall, as they have the ability to germinate at low temperatures (Kerr et al. 1993).

Seeding in spring avoids overwinter seed loss due to erosion and runoff, although seeding is often delayed by wet conditions. However, because spring seeding occurs later in the season, environmental conditions such as drought often limit growth potential of young seedlings (Pearson 1994). Late fall seeding allows dormancy to be broken over winter and enables seedlings to establish early in the growing season and in sufficient number to fully exploit soil and water resources (Steppuhn et al. 1993), while taking advantage of a longer growing season (Romo and Lawrence 1990). Fall seeding should be conducted late enough in the season that seeds will not germinate and grow before the winter. However, a prolonged period of warm fall weather may induce germination, leaving plants vulnerable in subsequent cold weather. In summary, environmental conditions during seedling establishment and length of the growing season, as determined by seeding date, may be important causes of the variation between fall and spring seeded plants.

Numerous studies support fall seeding of cool season species. Vallentine (1989) defined cool season species as those whose main growing seasons are the late fall and early spring. According to Cook et al. (1974), fall seeding is preferable for cool season grasses and legumes, assuming favorable soil moisture conditions occur. Frischknect (1959) found fall seeded mountain brome (*Bromus carinatus* Hook. and

Arn.) had faster growth and development than spring planted. Frischknecht (1959) attributed this in part to the ability of fall seeded grasses to begin growing earlier in the spring. Steppuhn et al. (1993) found fall seeded kochia (*Kochia scoparia* L.) produced more forage than spring seeded, which developed later and had undersized root systems which could not fully utilize available water. Pearson (1994) found similar results, attributing increased productivity of fall seeded wheat (*Triticum aestivum* L.) to favorable temperature and moisture conditions during early spring growth. Hull (1948), McWilliams (1955), Douglas et al. (1960), Young et al. (1994), and Ries and Hofmann (1996) all reported higher productivity and greater seedling establishment with fall seeding.

In contrast, there are few studies that support early spring seeding of cool season species. McGinnies (1960) found better establishment of introduced species from spring seeding. In tall grass revegetation studies in Manitoba, Morgan (1992) found spring seeding was more successful than fall seeding. Kerr et al. (1993) report spring seeding is preferred by the Alberta Environmental Centre in Vegreville because it enables plants to take advantage of early spring moisture.

Kilcher (1961) cautions that species react differently; therefore, results should be studied individually. For example, green needle grass (*Stipa viridula* Trin.) has higher productivity with fall seeding, while Russian wild rye (*Elymus junceus* Fisch.) has a narrow range of acceptable spring seeding dates (Kilcher 1961).

Ries and Hofmann (1996) found significant seeding date by year interactions due to changes in environmental conditions at repeated seeding dates in the northern Great Plains. Thus although certain seeding dates can be expected to provide good establishment because of favorable temperatures and precipitation, failures may occur when expected weather conditions do not occur. Ries and Hofmann (1996) concluded that the important factor in seeding is not the date but rather the weather and soil conditions that occur after seeding. Fowler (1982) found similar results which showed seasonal variation in the environment was responsible for the coexistence of some species.

2.2.5. Mowing

Non-seeded species, whether contributions from the seedbank or invasions from off-site, may significantly influence plant community development. This influence may be interpreted as positive, such as the facilitative contributions of annual species biomass to soil development and the establishment of ground cover to control soil erosion. However, non-seeded species, particularly perennials, may compete with seeded species for light, water, nutrients and space. Competition may limit the establishment, growth and survivability of the seeded plant community and impair successful development. In such cases, mowing may be implemented to control non-seeded species.

Mowing can be used to control non-seeded species if conducted at the appropriate time; prior to seed set in annuals and prior to carbohydrate store replenishment in perennials (Pelech 1997). However, mowing too early can actually stimulate weed growth with rapid seed head production (Leskiw 1978). Unfortunately, most existing literature focuses on the effect of mowing on native vegetation, and not on the control of non-seeded species in native vegetation.

Gerling et al. (1995) found early spring mowing increased soil temperatures, resulting in earlier spring growth and a slower growth rate of vegetative tillers in June. Hogg and Lieffers (1991) found mowing advanced soil thawing in spring by up to one month, compared to unmowed sites. In mowed plots, soil temperatures were warmest in the afternoon or evening, which the researchers believed promoted a higher rate of photosynthesis and growth, while helping to minimize carbon losses at night. Hesse and Salac (1972) found mowing delayed and extended the blooming period.

Pelech (1997) found mowing did not consistently affect the density or cover of native species. Gerling et al. (1995) found mowing increased tiller densities and reduced standing crop and tiller length of rough fescue (*Festuca hallii* (Vasey) Piper) in the first growing season following treatment. Brown (1997) found mowing stimulated a short-term increase in tillering of invasive smooth brome (*Bromus inermis* Leyss.)

Gerling et al. (1995) found inflorescence density increased with mowing during the previous growing season. Daubenmire (1968) found increased inflorescence production after defoliation is a common phenomenon in grasses translating to an increase in flower and seed production. Increased seed production from non-seeded species could cause an increase in density of non-seeded species the following year. This raises the question of the effectiveness of mowing as a management technique.

3.0. SUMMARY

Significant controversy and uncertainty regarding the processes and factors affecting native plant community development consumes current literature. Although the ecological benefits of mixed communities have been frequently debated, attempts to establish diverse communities have often failed due to competitiveness of seeded species (Call and Roundy 1991). An important challenge for ecological restoration is to determine the requirements of different species and the management practices which maximize ecological stability.

Lost in the confusion and uncertainty of plant community development theories is a simple comparison of the resulting vegetation communities of low versus high species richness of seed mixes. Regardless of the apparent (and debatable) merits of biodiversity, the results of a species richness comparison at the initial stages of community development would be of significant ecological and economical importance. The results of such an experiment would provide basic but essential information to aid in designing seed mixes for successful reclamation of disturbed environments.

There is tremendous need for basic information and understanding of factors affecting plant community development. Although site characteristics may, at times, be beyond control, the influence of management is significant and often underrated. A general appreciation of site capability and productivity is lacking in plant community development. Traditional agronomic rules may not apply to the use of native species. The journey towards successful reclamation must begin with an understanding of basic concepts, including the recommended season of seeding, seed mix composition and the use of mowing as a management technique.

The general objective of this research is to determine design and management techniques which are useful in native plant community development. Specific objectives are to determine a suitable season of seeding, to investigate mowing as a management technique and to study the relationship between the seed mix and the resulting plant community during the first two years of plant community development.

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CHAPTER II. DETAILED RESEARCH SITE CHARACTERISTICS AND EXPERIMENTAL DESIGN

1.0. SITE CHARACTERISTICS

1.1. Location

Research sites are located at the University of Alberta Ellerslie Research Station (NW-33-51-25-W4M) in southern Edmonton and Elk Island National Park, approximately 50 km east of Edmonton. The Elk Island sites are two fenced locations adjacent to Oster Lake (NW-32-53-20-W4M) and Tawayik Lake (NW-28-53-20-W4M), separated by a distance of approximately three km. Ellerslie is in the Aspen Parkland ecoregion; the Elk Island sites are technically in the Low Boreal Mixedwood ecoregion (Strong and Leggat 1992). Strong and Leggat's (1992) classification is based on a large scale and is not a suitable description for the smaller scale mosaic of grassland and aspen forest which is present at Oster Lake and Tawayik Lake. Thus, for this research, the area surrounding the Elk Island sites is classified as Aspen Parkland.

The Aspen Parkland is the second largest of the twelve ecoregions in Alberta, covering approximately 7.9 % of the province (Kerr et al. 1993). However, less than 5% of this area remains in its natural state (Wallis 1987). Most of the Aspen Parkland occurs north of the Mixed Grass and west of the Fescue Grass ecoregions, although two outliers occur in the Cypress Hills and near Grand Prairie. The Aspen Parkland ecoregion is one of the most productive agricultural zones in Alberta.

1.2. Topography

The Aspen Parkland ecoregion occurs in the Plains physiographic region of Alberta and is characterized by undulating to hummocky glacial till deposits (Crown 1977). The terrain has numerous glacial landforms which reflect the activities of glacial fronts and ice blocks during the last glacial period. The slopes of the site locations are fairly level (less than 2%).

1.3. Hydrology

Due to the hummocky topography most soils are moderately well to well drained. Areas of poorly and very poorly drained soils are located in depressional and low-lying positions (Crown 1977). Both the Ellerslie and Elk Island sites are located in moderately well drained topographic positions.

1.4. Geology

Ellerslie and Elk Island National Park are both in the Interior Plains region. The Interior Plains are composed of sedimentary bedrock overlain by a thick mantle of glacial drift (Douglas 1970). Although the composition of the till varies due to the nature of the underlying bedrock, it is generally a clay loam texture. All sites are underlain by late Cretaceous bedrock of the Edmonton formation. This is a brackish water formation composed of sandy shales and bentonitic sandstone, clay and coal seams.

1.5. Soils

The soil at the Ellerslie site is a Black Chernozem and is mapped as the Malmo soil series (Bowser et al. 1962). There is a transition along the plots from Gleyed in the west and central portions to Gleyed Eluviated in the eastern portion (Hammermeister 1998). The soil is a silty clay loam that developed on lacustrine material. It is rated as having high water storage, good drainage, low salinity and high organic matter content (Bowser et al. 1962).

Within Elk Island, soils are not mapped to the series level, but are assigned units that reflect the dominant soil order and great group. Oster Lake is mapped as soil unit MCO 3, Tawayik as MYW 3 (Crown 1977). The soil at Oster Lake is a Dark Gray Luvisol (Hammermeister 1998). At Tawayik Lake there is a gradient from a Dark Gray Luvisol in the northeast corner to a Gleyed Dark Gray Luvisol in the southwest corner. Both soils are developed on fine textured glaciolacustrine sediments. Oster Lake soil is a silty clay loam texture and Tawayik Lake soil is a clay loam texture (Crown 1977).

1.6. Climate

The Aspen Parkland ecoregion is an interaction of boreal and prairie climates, resulting in a subhumid to humid continental climate (Strong and Leggat 1992). Mean annual precipitation is 450 mm, 78% of which occurs as summer precipitation (Strong and Leggat 1992). The characteristic distinguishing this ecoregion from grasslands is the abundance of precipitation in July rather than early spring. The increase in moisture during the middle and end of the growing season reduces moisture stress on vegetation; a factor which may be critical both to survival of aspen (*Populus tremuloides* Michx.) and the success of revegetation programs.

The frost free period is approximately 90 days, which is sufficient for the growth of cereal crops (Strong and Leggat 1992). Generally, the Aspen Parkland ecoregion receives fewer than 15 chinooks per winter (Strong and Leggat 1992). This decreased chinook activity, coupled with lower winter temperatures, prolongs snow cover and increases snow depth compared to grassland ecoregions.

1.7. Vegetation

Moss (1955) described parkland as "a mosaic of prairie patches and aspen groves, with prairie occupying the drier situations and aspen the more moist and sheltered places". The Aspen Parkland ecoregion can be divided into three subregions: the Groveland, Willow and Aspen (Strong and Leggat 1992). The Groveland Subregion occurs near the Cypress Hills and the Willow Subregion occurs from the Porcupine Hills to north of Calgary. The Aspen Subregion, where the research sites are located, is dominated by clones of aspen interspersed by patches of grassland. The Aspen Subregion occurs adjacent to mesic ecoregions and is, therefore, the more mesic subregion of the Aspen Parkland. The mesic soil moisture and humidity conditions favor the establishment of diverse understory vegetation.

2.0. EXPERIMENTAL DESIGN

The research sites are split plots (1998) and split-split plots (1999) (Figures 2.1 and 2.2). Each site is divided into blocks. There are four blocks at Ellerslie and two each at Oster and Tawayik Lakes. Each block is divided lengthwise as a split plot of fall and spring seeded treatments. In June 1998, the fall seeded treatment was split in half lengthwise (split plot design) into mowed and unmowed treatments. In August 1998, both the fall and spring seeded treatments were split in half lengthwise (split-split plot design) into mowed and unmowed treatments. Within each season and mowing treatment of each block are four seed mixes. Therefore, each block contains four plots of fall and four of spring seeded mixtures. Each plot is 12.6 m long and 8.84 m wide, and is bordered on all sides by a 1 m interplot area.

3.0. SEED MIX TREATMENTS AND SEEDING

3.1. Seed Mix Design

Four seed mixes were used for this research (Table 2.1). All species present in the mixes are common to the Aspen Parkland ecoregion and were obtained from a source within Alberta. Refer to Appendix A for supplemental information on all species. All life history data is from Hardy BBT Limited (1989), unless otherwise noted. Naming is according to Moss (1983) and Pavlick and Looman (1984). Common names are adapted from Vance et al. (1992).

The mixes were designed to provide equal amounts of pure live seed (PLS) of each species within the plant type classification (grass or forb). Theoretically, the equal number of PLS per species should yield equal species density and plant density. The grass-forb mixes were 70% grasses and 30% forbs, representative of the percent cover and species number of grasses to forbs in the Aspen Parkland. Although the number of forb species is larger than grasses, the percent cover of forbs is less than that of grass. Therefore, the 70:30 ratio reflects a large number of forb species, comprising a relatively small amount of the percent ground cover. The percent composition of grasses or forbs is divided by the number of grass or forb species, to give the percent composition of each species. This equality among species should avoid numerically favoring one species over another and control the amount of rhizomatous wheatgrasses in the mix. According to Gill (1996), no more than 20% rhizomatous wheatgrasses should be used in revegetation seed mixes. Higher amounts tend to result in competitive exclusion. Gill (1996) also found the density of rhizomatous wheatgrasses increases over time. Thus, by lowering the percentage of wheatgrasses in a seed mix, densities unrepresentative of native communities can be avoided.

3.2. Seed Bed Preparation

The site at Ellerslie has been used for agricultural research for several years (Table 2.2). The two Elk Island Park sites were established for research in 1994 (Table 2.2).

All sites were rototilled in August 1997 to a depth of 10 cm. In late August, once weeds re-established following cultivation, the sites were sprayed with the recommended rate (3 L ha^{-1}) of Roundup (glyphosate). The sites were rototilled again in early September and sprayed September 29, 1997. The rototilling was necessary to loosen the soil crust and facilitate fall seeding. It was also necessary to rototill the soil in May 1998 before spring seeding.

There was no fertilizer added at the time of fall or spring seeding; however, the Ellerslie site has a history of fertilization for agricultural research. Fertilization was not conducted at any time during this research.

3.3. Seed Mix Preparation

Seed mixes were based on PLS and the number of seeds per kilogram. Three hundred seeds of each species were counted and weighed. Chaff and other non-seed matter was included in the weight, because of the immense time that would have been required to satisfactorily remove it. For accuracy, the counting and weighing were repeated twice; the data were then converted into the number of seeds per kilogram. Those species which were not received with a seed certificate were then sent to 20/20

Seed Labs Ltd. for purity and germination tests to provide the PLS number. Before weighing began, the calculations were redone to reflect the PLS and seed weight for the seeds used in this research.

The desired seeding rate was 200 PLS m^{-2}, lower than the common seeding rate of 300 PLS m^{-2}, to allow for invasion of species from off-site. The width of the plot was divided by the width of the seeder to calculate the number of seed rows per plot. The amount of PLS of each species was then divided by the number of seed rows (40) to calculate the PLS per row. PLS was divided by the number of seeds per kilogram so seed rows could be prepared according to weight and not number of seeds. Each seed mix was prepared by weighing the amount of seed per species per row into small envelopes (refer to Appendix B for detailed calculations). Then, one seed row (small envelope) of each species in the mix was combined into a larger envelope. Therefore, this larger envelope contained the seed of all species in the mix, for one seed row. One large envelope was placed in each seeder cone.

3.4. Seeding

Grasses were drill seeded October 4 and 5, 1997 and May 24, 1998 using an eight cone drill seeder. Despite previous discussion that it was more desirable to broadcast small grass seeds, all species were drill seeded. This removed any effect which could be attributed to differences in seeding method of grasses. Seeding date was largely dependent on weather and site conditions. The eight cone drill seeder was selected because it provided the ability to control the amount of seed per species, per seed row.

The seeding rate was 200 PLS per m^2. Each seed row contained equal numbers of PLS of each grass species. Duck and goose starter was used as a carrier (refer to Appendix B for supplemental information) at a rate of 50 cm^3 per row. Rows were placed approximately 20 cm apart as dictated by the seed drill design and seeds placed at a depth of 2.5 cm. Forb seeds were broadcast October 11 and 12, 1997 and May 24, 1998. Duck and goose starter was used as a carrier. Ideally, the forb seeds should have been harrowed to a depth of roughly 1 cm or less, to provide better soil-seed contact (Wasser 1982); however, wet weather prohibited site access in the fall.

Therefore, the forb seeds were not harrowed in the spring either for consistency in methods.

It was necessary to store seed over the winter of 1997/98 for spring seeding. The primary concern was to store the seeds in a cool, dry location. There was concern for humidity levels which could induce germination. The seeds were stored in a freezer from November 1, 1997 until May 1, 1998 to keep seeds at a low humidity level; it was not intended to imitate the over-winter cold stratification process that seeds undergo in the ground over winter.

4.0. SOIL SAMPLING AND ANALYSES

4.1. Sampling

Penetration resistance was measured in May 1998 (following spring seeding) using a CN-973 Soil Test proving ring cone penetrometer. Ten readings were taken in each block, at 2.5, 5, 7.5, 10 and 15 cm increments. Soil cores were taken at the same time from interplot areas in eight randomly selected locations in each plot to a depth of 60 cm (0 to 5, 5 to15, 15 to 30, 30 to 45 and 45 to 60). The samples from each block were composited in the five separate increments from each of the eight blocks, for a total of 40 samples. Immediately following sampling, the samples were air-dried.

4.2. Analyses

The soil was analyzed for exchangeable nitrate- and ammonium-nitrogen using a 5:1 potassium chloride extract (2M) (Carter 1993). Soil pH and electrical conductivity were analyzed according to Carter (1993). Organic carbon was analyzed using the Walkley-Black method (Carter 1993). Percent sand, silt and clay was determined using the hydrometer method outlined in McKeague (1978). Phosphate-phosphorus was determined using acetate flouride extraction; potassium was determined using ammonium acetate extraction; and sulphate-sulfur was determined using 0.001 M calcium chloride extraction (McKeague 1978). Nutrient analyses were completed by Norwest Labs; all other soil analyses were conducted at the University of Alberta.

4.3. Results

Penetration resistance (PR) is the same at all sites to 5 cm depth but at the 15 cm depth, Ellerslie has slightly lower PR than either Elk Island site (Table 2.3). Below this depth, Ellerslie has much lower PR than either Elk Island site. The Ellerslie site had greater PR in spring than fall seeded treatments, while there was no noticeable trend for spring versus fall seeded treatments in either Elk Island site.

Soil chemical and physical properties of each site are listed in Table 2.4. According to Macyk et al. (1993), soil pH at all sites is rated as fair to good. Electrical conductivity (EC) and organic carbon are both rated as good. Generally the sites are similar and there is no obvious trend for pH, percent organic carbon, ammonium-nitrogen and potassium. Ellerslie, however, has higher EC, nitrate-nitrogen and sulphate-sulphur levels, but lower phosphorous levels than either Elk Island site.

Tawayik has the highest percent sand content, Oster the highest silt and Ellerslie the highest clay (Table 2.4).

5.0. METEOROLOGICAL MEASUREMENTS

5.1. Methods

Air temperature and precipitation data were collected at meteorological stations at Ellerslie and the Elk Island warden station, approximately 10 km from the sites. Ellerslie data were compiled by the University of Alberta; Elk Island data by Environment Canada. Average monthly temperature and total monthly precipitation were recorded and compared to long-term averages.

Snow density was measured on March 1, 1999 using a 7.62 cm diameter plastic pipe with height markings on the outer side. The pipe was driven into the snow, the snow depth recorded and the volume of snow in the pipe was placed in a labeled bag. The melted snow was weighed and density calculated. Due to limitations on site access, snow depth could only be measured at the Ellerslie site.

5.2. Results

At the Elk Island sites summer 1997, winter 1997/1998 and summer 1998 were warmer than the long term average (Table 2.5.a) (Environment Canada 1994, 1999). The same period of time was generally drier than the long-term average, especially during summer 1998 (Environment Canada 1999). Winter 1999 was warmer and had more precipitation than the long-term average; spring 1999 was slightly cooler than the long-term average and was much drier than the long-term average from April to June.

At Ellerslie, summer 1997 and 1998 were warmer than the long-term average. Fall and winter 1997 and 1998 were also drier than the long-term average (Table 2.5.b.) (CLRRU 1999, Environment Canada 1994). Winter 1999 was warmer and drier than the long-term average, but was followed by a spring that was generally cooler and wetter than the average.

Snow density differed only slightly between fall mow and fall ummow treatments (Table 2.6). Any visual difference in the amount of standing biomass or litter between the mowing treatments was not evident in the snow density. The depth and volume of the snow in the two treatments was also very similar.

There was a difference between the two fall treatments and the spring unmow treatment. The spring treatment had a lower mean density, but a slightly higher mean depth and volume. In other words, the snow pack in the spring seeded treatment was deeper and larger in volume but less dense than the snow in either fall seeded treatment. The fall seeded treatment likely had more vegetation biomass, allowing it to trap snow in a dense pack.

6.0. SEEDBANK AND RECONNAISSANCE SURVEYS

6.1. Survey

The seedbank was expected to be a seed contributor; therefore, identification of its composition was of use in explaining the origin of non-seeded species found in the plots. A survey of non-seeded species in each block was conducted monthly throughout the 1998 growing season. Observations of the species present were made. This method of data collection was advantageous because there was no limitation placed on the depth of seedbank to be studied and emergence occurred under natural, not greenhouse, conditions.

A reconnaissance survey of surrounding vegetation was also conducted monthly during the 1998 season. This informal survey noted the species present growing off-site which were potential seed contributors. The perimeter of each block was walked, to a distance of 10 m from the corner of the blocks. Species observed were listed by name; no measurements were taken.

6.2. Results

At Tawayik Lake, the seedbank had an impressive species richness, with maple-leaved goosefoot *(Chenopodium gigantospermum* Aellen) predominant (Table 2.7). Although most of the seedbank species were agricultural weeds, there were several native species, including fireweed (*Epilobium angustifolium* L.) and strawberry (*Fragaria virginiana* Duchesne). Many species found off-site (Table 2.8) were also found in the plots. Common yarrow (*Achillea millefolium* L.) and American vetch (*Vicia americana* Muhl ex. Willd) were found both off-site and in the seedbank.

At Oster Lake, the predominant seedbank species was lamb's quarters (*Chenopodium album* L.) (Table 2.7). Although most of the seedbank species were agricultural weeds, there were a few native species, including strawberry. Again, common yarrow and American vetch were found off-site (Table 2.8) and in the seedbank.

Because the area surrounding the plots at Ellerslie was frequently cultivated, few species were present (Table 2.8). By far, the most predominant species off-site was Canada thistle (*Cirsium arvense* (L.) Scop.). In certain plots, this was also a significant contribution from the seedbank. With the exception of American vetch, the seedbank was composed of agricultural weeds (Table 2.7).

7.0. MANAGEMENT

7.1. Herbicide And Cultivation

At the Ellerslie plots, Canada thistle became a problem early in the 1998 growing season. Each thistle was spot sprayed with Roundup at a 1:50 concentration periodically throughout summers 1998 and 1999. In June 1998, the interplot areas were mowed to facilitate plot access. No mowing was necessary at either Elk Island site.

A 10 m strip around the Ellerslie site was cultivated several times throughout summers 1998 and 1999 as required by the research station policy. No cultivation was done around the plots at Elk Island.

7.2. Mowing

Although non-seeded species (weeds) play a role in plant community development, their presence is often detrimental to the development of native vegetation. Whole-plot application of a broadleaf herbicide was not an option because it could potentially kill the seeded forbs; mowing was therefore chosen as the method of control.

The plots were divided into split plots for mowing management. A strip (half of each fall seeded plot) was mowed in June 1998 to a height of 15 cm to prevent seed set; the spring plots were not sufficiently developed to justify mowing at that time. Mowed vegetation was not removed. The strips of both fall and spring seeded plots were mowed in early August 1988, after the 1998 vegetation assessment was conducted. No mowing was done in summer 1999 as there was not an abundant growth of annual species.

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Table 2.1. Seed mixes seeded at Ellerslie and Tawayik Lake and Oster Lake, Elk Island National Park

Mix	Scientific name	Common name
1	*Agropyron dasystachyum* (Hook.) Scribn	Northern wheatgrass
	Agropyron trachycaulum (Link) Malte var. *trachycaulum*	Slender wheatgrass
	Bouteloua gracilis (HBK) Lag.	Blue grama grass
	Festuca hallii (Vasey) Piper	Plains rough fescue
	Koeleria macrantha (Ledeb.) Schult.	June grass
	Stipa viridula Trin.	Green needle grass
2	*Agropyron dasystachyum* (Hook.) Scribn	Northern wheatgrass
	Agropyron trachycaulum (Link) Malte var. *trachycaulum*	Slender wheatgrass
	Agrostis stolonifera L.	Red top
	Bouteloua gracilis (HBK) Lag.	Blue grama grass
	Bromus carinatus Hook. and Arn.	Mountain brome grass
	Festuca hallii (Vasey) Piper	Plains rough fescue
	Festuca ovina L.	Sheep fescue
	Koeleria macrantha (Ledeb.) Schult	June grass
	Poa palustris L.	Fowl bluegrass
	Stipa viridula Trin.	Green needle grass
3	Mix 1 plus:	
	Achillea millefolium L.	Common yarrow
	Aster laevis L.	Smooth aster
	Gaillardia aristata Pursh	Gaillardia
	Linum lewisii Pursh	Wild blue flax
	Monarda fistulosa L.	Wild bergamot
	Petalostemon purpureum (Vent.) Rydb.	Purple prairie clover
	Ratibida columnifera (Nutt.) Wooton and Standl.	Prairie coneflower
	Solidago canadensis L.	Canada goldenrod
	Solidago missouriensis Nutt.	Low goldenrod
	Vicia americana Muhl.	American vetch
4	Mix 2 plus:	
	Achillea millefolium L.	Common yarrow
	Aster laevis L.	Smooth aster
	Gaillardia aristata Pursh	Gaillardia
	Linum lewisii Pursh	Wild blue flax
	Monarda fistulosa L.	Wild bergamot
	Petalostemon purpureum (Vent.) Rydb.	Purple prairie clover
	Ratibida columnifera (Nutt.) Wooton and Standl.	Prairie coneflower
	Solidago canadensis L.	Canada goldenrod
	Solidago missouriensis Nutt.	Low goldenrod
	Vicia americana Muhl.	American vetch

Table 2.2. Crop, fertilizer and herbicide history of Ellerslie and Tawayik Lake and Oster Lake, Elk Island National Park

Year	Crop	Fertilizer Rate, Grade	Herbicide
Tawayik Lake and Oster Lake[1]			
Spring 1997	N/A	N/A	Cultivation, Roundup
1996	N/A	N/A	Cultivation, Roundup
1995	N/A	N/A	Cultivation, Roundup
1994	Native vegetation	N/A	Cultivation, Roundup
Pre 1994	Site unbroken		
Ellerslie[2]			
Spring 1997	Canola	N/A	Edge
1996	Fallow	N/A	N/A
1995	Wheat	44 kg ha^{-1} 11-51-0	Dicamba
1994	Canola	55 kg ha^{-1} 11-51-0	Edge
1993	Red clover	N/A (*inoculated)	N/A
1992	Wheat	44 kg ha^{-1} 11-51-0	Dicamba
1991	Fallow	N/A	N/A
1990	Wheat	30 kg ha^{-1} 11-51-0	Dicamba
1989	Fallow	N/A	N/A
1988	Hay	N/A	N/A
Pre 1988	Hay	N/A	N/A

[1] Dana Bush, personal communication

[2] Dick Puurveen, personal communication

N/A No crop seeded, no fertilizer applied

Table 2.3. Average penetration resistance (Mpa) in fall and spring seeded seeded treatments

	Tawayik Lake, Elk Island National Park					
	Block 1		Block 2			
Depth (cm)	Fall	Spring	Fall	Spring	Mean	SD
2.5	0.5	0.3	0.1	0.1	0.3	0.2
5.0	0.7	0.7	0.6	0.3	0.6	0.2
7.5	1.5	1.6	1.3	1.6	1.5	0.1
10.0	2.3	2.5	2.1	2.2	2.3	0.2
15.0	2.0	1.8	1.8	1.7	1.8	0.1

	Oster Lake, Elk Island National Park					
	Block 3		Block 4			
Depth (cm)	Fall	Spring	Fall	Spring	Mean	SD
2.5	0.3	0.3	0.4	0.3	0.3	0.1
5.0	0.5	0.4	0.9	0.6	0.6	0.2
7.5	1.1	0.9	2.0	1.4	1.4	0.5
10.0	2.1	1.7	2.3	1.7	1.9	0.3
15.0	2.7	2.1	2.0	1.4	2.1	0.5

					Ellerslie					
Depth	Block 5		Block 6		Block 7		Block 8			
(cm)	Fall	Spring	Fall	Spring	Fall	Spring	Fall	Spring	Mean	SD
2.5	0.2	0.4	0.2	0.3	0.3	0.4	0.2	0.5	0.3	0.1
5.0	0.3	0.5	0.2	0.4	0.3	0.4	0.3	0.5	0.4	0.1
7.5	0.5	0.6	0.3	0.4	0.4	0.5	0.4	0.5	0.4	0.1
10.0	0.4	0.7	0.4	0.5	0.5	0.7	0.4	0.6	0.5	0.1
15.0	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.0

Table 2.4. Soil chemical and physical properties at Ellerslie and Tawayik Lake and Oster Lake, Elk Island National Park

		Chemical properites			Macronutrients (ppm)					Physical properties		
Site	Depth (cm)	pH	EC (Umhos)	% OC	NO3-N	NH4-N	P	K	S	% Sand	% Silt	% Clay
Tawayik Lake	0-5	6.0	393.5	6.9	58.4	10.1	31.0	362.5	19.8	44.8	40.8	14.4
	5-15	6.4	165.0	2.1	19.9	4.5	9.5	99.0	9.8	46.4	39.7	14.0
	15-30	6.8	177.4	2.1	18.4	4.4	12.5	123.5	14.0	45.6	37.2	17.3
	30-45	7.4	233.5	1.5	14.5	5.1				45.4	24.0	30.6
	45-60	7.8	326.7	0.9	8.0	3.3				47.0	21.4	31.6
Oster Lake	0-5	5.8	233.5	3.2	38.0	6.4	19.5	286.0	5.1	33.1	49.2	17.7
	5-15	6.1	204.6	2.4	33.9	5.6	16.0	233.5	4.2	31.1	49.9	19.0
	15-30	6.2	157.6	2.2	33.1	6.6	14.5	216.5	4.2	30.1	49.7	20.2
	30-45	5.5	148.5	1.2	20.5	5.4				29.3	34.8	36.0
	45-60	5.5	148.5	1.2	19.0	5.7				29.3	37.1	33.7
Ellerslie	0-5	6.7	390.6	5.8	120.6	5.0	11.3	287.0	70.3	21.7	44.2	34.0
	5-15	6.7	430.7	5.6	134.3	5.0	9.3	256.0	79.0	26.9	39.4	33.7
	15-30	6.7	380.3	4.3	117.3	4.6	7.8	230.0	82.5	22.6	43.0	34.4
	30-45	6.8	329.6	2.7	99.3	3.9				21.1	39.4	39.5
	45-60	6.7	353.1	1.6	103.2	4.0				18.6	34.4	47.0

Table 2.5.a. Mean daily temperature and total monthly precipitation at Elk Island National Park meteorological station

					Mean daily temperature (°C)							
Year(s)	January	February	March	April	May	June	July	August	September	October	November	December
1966-1975	-16.8	-9	-7.6	0.5	9.6	13.7	15.3	14.9	10.9	1.5	-6.5	-9.3
1981-1983	-11.4	-10.9	-5.2	4.4	11.0	14.6	16.5	15.1	9.1	4.6	-7	-10.6
1997					11.3	15.7	17.7	17.5	13.5	4.1	-1.6	-2.2
1998	-16.7	-4.8	-3.8	7.7	15.4	14.0	18.9	18.8	12.3	6.2		
1999	-14.0	-8.0	-3.9	4.9	9.2	13.5	14.7					

					Total monthly precipitation (mm)							
Year(s)	January	February	March	April	May	June	July	August	September	October	November	December
1966-1975	24.0	16.8	29.9	10.4	27.1	65.9	101.3	82.8	46.7	34.1	25.4	12.9
1981-1983	13.8	13.6	21.0	20.6	47.3	93.1	147.6	52.0	65.6	19.7	13.1	16.4
1997					90.6	139.4	19.8	49.2	22.8	35.8	9.0	1.3
1998	35.2	0.8	19.0	28.1	35.0	15.8	22.0	19.6	54.6	25.8		
1999	29.7	36.7	33.0	2.7	9.0	22.2	101.6					

Table 2.5.b. Mean daily temperature and total monthly precipitation at Ellerslie meteorological station[1]

					Mean daily temperature (°C)							
Year(s)	January	February	March	April	May	June	July	August	September	October	November	December
1964-1993	-15.6	-11.1	-5.5	3.6	10.6	14.1	16.0	15.2	9.7	4.7	-5.8	-12.9
1997	-15.1	-3.9			14.4	17.0	18.8	18.4	16.5			
1998	-16.8							17.1	12.3	5.4	-5.3	-11.4
1999	-14.7	-8.9	-6.1	3.8	6.4	10.7	12.5					

					Total monthly precipitation (mm)							
Year(s)	January	February	March	April	May	June	July	August	September	October	November	December
1964-1993	24.5	15.1	15.8	18.2	42.9	82.6	89.8	63.2	45.7	17.8	16.2	22.9
1997	0.0	0.0			16.2	121.0	51.6	54.2	45.4			
1998	0.0							0.2	44.0	31.4	14.8	2.6
1999	0.2	2.6	19.6	28.0	78.0	28.8	79.6					

[1] blank cells indicate data was not available

Table 2.6. Mean snow depth, volume and density of three season-mow treatments in March 1999 at Ellerslie

Season-mow	Depth (cm)	Volume (cm^3)	Density ($g\ cm^{-3}$)
Fall mow	43.8	1994.3	0.23
	3.3[1]	150.6	0.02
Fall unmow	43.0	1960.1	0.23
	2.6	117.7	0.01
Spring unmow	45.0	2051.3	0.20
	1.2	52.6	0.05

[1] standard deviation

Table 2.7. Seedbank inventory of vegetation within plots

Tawayik Lake

Scientific name	Common name
Achillea millefolium L.	Common yarrow
Amaranthus blitoides L.	Prostrate pigweed
Brassica campestris L.	Canola
Brassica sp.	Mustard
Capsella bursa-pastoris (L.) Medic	Shepherd's purse
Chenopodium album L.	Lamb's quarters
Chenopodium capitatum (L.) Aschers	Strawberry blite
Chenopodium gigantospermum Aellen	Maple-leaved goosefoot
Cirsium arvense (L.) Scop.	Canada thistle
Corydalis aurea Willd.	Golden corydalis
Crepis tectorum L.	Narrow-leaved hawksbeard
Descurainia sophia (L.) Webb	Flixweed
Draba nemorosa L.	Yellow whitlow grass
Epilobium angustifolium L.	Fireweed
Epilobium glandulosum (Lehm.) Koch & Raven	Purple-leaved willowherb
Erucastrum gallicum (Willd.) Schulz	Dog mustard
Fragaria virginiana Duchesne	Wild strawberry
Galeopsis tetrahit L.	Hempnettle
Geranium bicknellii Britt.	Bicknell's geranium
Geum aleppicum Jacq.	Yellow avens
Matricaria matricaroides (Less.) Porter	Pineappleweed
Melilotus officinalis (L.) Lam.	Sweetclover
Phleum pratense L.	Timothy
Plantago major L.	Plantain
Poa annua L.	Annual bluegrass
Poa sp.	Bluegrass
Polygonum aviculare L.	Prostrate knotweed
Polygonum convolvulus L.	Wild buckwheat
Polygonum lapathifolium L.	Knowtweed
Polygonum persicaria L.	Lady's thumb
Rubus idaeus L.	Wild raspberry
Senecio vulgaris L.	Common groundsel
Silene noctiflora L.	Night-flowering catchfly
Solidago canadensis L.	Canada goldenrod
Stachys palustris L.	Marsh hemp nettle
Stellaria media (L.) Cyrill.	Chickweed
Taraxacum officinale Weber	Dandelion

Table 2.7. Seedbank inventory of vegetation within plots (cont'd)

Tawayik Lake

Scientific name	Common name
Thlaspi arvense L.	Stinkweed
Trifolium hybridum L.	Alsike clover
Trifolium pratense L.	Red clover
Triticum aestivum L.	Wheat
Urticia dioica L.	Stinging nettle
Vicia americana Muhl ex. Willd	American vetch

Oster Lake

Scientific name	Common name
Achillea millefolium L.	Common yarrow
Amaranthus retroflexus L.	Redroot pigweed
Aster laevis L.	Smooth aster
Brassica campestris L.	Canola
Brassica sp.	Mustard
Bromus inermis Leyss.	Smooth brome
Capsella bursa-pastoris (L.) Medic	Shepherd's purse
Carex sp.	Sedge
Chenopodium album L.	Stinkweed
Chenopodium gigantospermum Aellen	Maple-leaved goosefoot
Cirsium arvense (L.) Scop	Canada thistle
Corydalis aurea Willd.	Golden corydalis
Crepis tectorum L.	Narrow-leaved hawksbeard
Descurainia sophia (L.) Webb	Flixweed
Dracocephaum parviflorum Nutt.	American dragonhead
Epilobium glandulosum (Lehm.) Kock & Raven	Purple-leaved willowherb
Equisetum spp.	Horsetail
Fragaria virginia Duchesne	Wild strawberry
Galeopsis tetrahit L.	Hempnettle
Geranium bicknellii Britt.	Bicknell's geranium
Geum aleppicum Jacq.	Yellow avens
Lactuca pulchella (Pursh) DC.	Prickly blue lettuce
Matricaria matricaroides (Less.) Porter	Pineappleweed
Melilotus officinalis (L.) Lam	Sweetclover
Oenothera biennis L.	Yellow evening primrose
Phleum pratense L.	Timothy
Plantago major L.	Plantain

Table 2.7. Seedbank inventory of vegetation within plots (cont'd)

Oster Lake

Scientific name	Common name
Polygonum aviculare L.	Prostrate knotweed
Polygonum convolvulus L.	Wild buckwheat
Populus balsamifera L.	Balsam poplar
Silene noctiflora L.	Night-flowering catchfly
Solidago canadensis L.	Canada goldenrod
Sonchus arvensis L.	Sow thistle
Taraxacum officinale Weber	Dandelion
Thlaspi arvense L.	Stinkweed
Trifolium hybridum L.	Alsike clover
Trifolium pratense L.	Red clover
Trifolium repens L.	White clover
Triticum aestivum L.	Wheat
Urtica dioica L.	Stinging nettle
Vicia americana Muhl ex. Willd	American vetch

Ellerslie

Scientific name	Common name
Achillea millefolium L.	Common yarrow
Agropyron repens (L.) Beauv.	Quackgrass
Amaranthis blitoides L.	Prostrate pigweed
Brassica campestris L.	Canola
Capsella bursa-pastoris (L.) Medic	Shepherd's purse
Chenopodium album L.	Lamb's quarters
Chenopodium capitatum (L.) Aschers	Maple-leaved goosefoot
Cirsium arvense (L.) Scop	Canada thistle
Corydalis aurea Willd	Golden corydalis
Crepis tectorum L.	Narrow-leaved hawksbeard
Descurainia sophia (L.) Webb	Flixweed
Dracocephaum parviflorum Nutt.	American dragonhead
Equisetum sp.	Horsetail
Erysimum cheiranthoides L.	Wormseed mustard
Galeopsis tetrahit L.	Hempnettle
Medicago sativa L.	Alfalfa
Plantago major L.	Plantain
Poa sp.	Bluegrass
Polygonum convulvulus L.	Wild buckwheat

Table 2.7. Seedbank inventory of vegetation within plots (cont'd)

Ellerslie

Scientific name	Common name
Polygonum lapathifolium L.	Green smartweed
Polygonum persicaria L.	Lady's thumb
Portulaca oleracea L.	Purslane
Sonchus arvensis L.	Sow thistle
Spergula arvensis L.	Corn spurry
Stellaria media (L.) Cyrill	Chickweed
Taraxacum officinale Weber	Dandelion
Thlaspi arvense L.	Stinkweed
Trifolium hybridum L.	Alsike clover
Trifolium pratense L.	Red clover
Vicia americana Muhl ex. Willd	American vetch

Table 2.8. Reconnaisance survey of vegetation surrounding plots

Tawayik Lake

Scientific name	Common name
Achillea millefolium L.	Common yarrow
Agrimonia striata Michx.	Agrimony
Androsace septentrionalis L.	Fairy candelabra
Aster laevis L.	Smooth aster
Capsella bursa-pastoris (L.) Medic	Shepherd's purse
Chenopdium capitatum (L.) Aschers.	Strawberry blite
Chenopodium album L.	Lamb's quarters
Chenopodium gigantospermum Aellen	Maple-leaved goosefoot
Cirsium arvense (L.) Scop.	Canada thistle
Descurainia sophia (L.) Webb	Flixweed
Epilobium angustifolium L.	Fireweed
Galeopsis tetrahit L.	Hemp nettle
Galium boreale L.	Northern bedstraw
Monarda fistulosa L.	Wild bergamot
Muhlenbergia cuspidata (Torr.) Rydb.	Plains muhly
Phleum pratense L.	Timothy
Poa pratensis L.	Kentucky bluegrass
Populus balsamifera L.	Balsam poplar
Populus tremuloides Michx.	Trembling aspen
Potentilla arguta Pursh	White cinquefoil
Potentilla norvegica L.	Rough cinquefoil
Ribes hirtellum Michx.	Wild gooseberry
Rubus idaeus L. var strigosus	Wild red raspberry
Solidago canadensis L.	Canada goldenrod
Solidago missouriensis Nutt.	Low goldenrod
Symphoricarpos occidentalis Hook.	Western snowberry
Taraxacum officinale Weber	Dandelion
Thlaspi arvense L.	Stinkweed
Trifolium hybridum L.	Alsike clover
Trifolium repens L.	White clover
Urtica dioica L.	Stinging nettle
Vicia americana Muhl ex. Willd	American vetch

Table 2.8. Reconnaisance survey of vegetation surrounding plots (cont'd)

Oster Lake

Scientific name	Common name
Achillea millefolium L.	Common yarrow
Androsace septentrionalis L.	Fairy candelabra
Antennaria parvifolia Nutt.	Pussytoes
Aster conspicuus Lindl.	Showy aster
Aster laevis L.	Smooth aster
Beckmannia syzigachne (Steud.) Fern.	Slough grass
Bromus inermis L.	Smooth brome
Carex aquatilis Wahlenb.	Water sedge
Carex spp.	Sedge
Cerasium vulgatum L.	Mouse-eared chickweed
Chenopdium capitatum (L.) Aschers.	Strawberry blite
Chenopodium album L.	Lamb's quarters
Cirsium arvense (L.) Scop.	Canada thistle
Collomia linearis Nutt.	Collomia
Descurainia sophia (L.) Webb	Flixweed
Equisteum arvense L.	Field horsetail
Fragaria glauca (S. Wats.) Rydb	Smooth wild strawberry
Fragaria virginiana Duchesne	Wild strawberry
Galeopsis tetrahit L.	Hemp nettle
Geum aleppicum Jacq.	Yellow avens
Lathyrus ochroleucus Hook.	White vetchling
Lathyrus venosus Muhl.	Wild peavine
Lithospermum spp.	Puccoon
Monarda fistulosa L.	Wild bergamot
Muhlenbergia cuspidata (Torr.) Rydb.	Plains muhly
Phleum pratense L.	Timothy
Plantago major L.	Common plantain
Poa palustris L.	Fowl bluegrass
Poa pratensis L.	Kentucky bluegrass
Polygonum aviculare L.	Prostrate knotweed
Populus balsamifera L.	Balsam poplar
Populus tremuloides Michx.	Trembling aspen
Potentilla arguta Pursh	White cinquefoil
Ribes hirtellum Michx.	Wild gooseberry
Rubus idaeus L. var strigosus	Wild red raspberry
Salix spp.	Willow
Solidago canadensis L.	Canada goldenrod

Table 2.8. Reconnaisance survey of vegetation surrounding plots (cont'd)

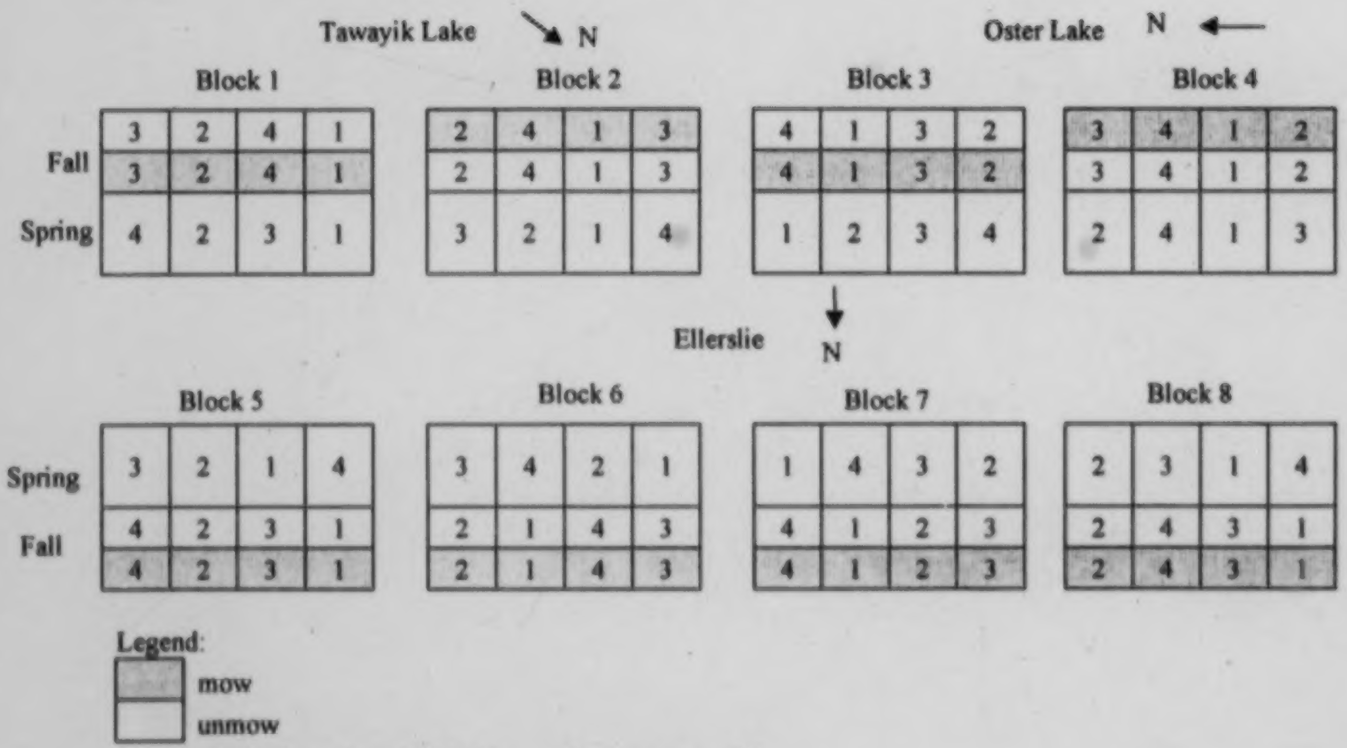
Oster Lake continued

Scientific name	Common name
Symphoricarpos occidentalis Hook.	Western snowberry
Taraxacum officinale Weber	Dandelion
Thlaspi arvense L.	Stinkweed
Trifolium hybridium L.	Alsike clover
Urtica dioica L.	Stinging nettle
Vicia americana Muhl ex. Willd	American vetch
Viola adunca J.E. Smith	Early blue violet

Ellerslie

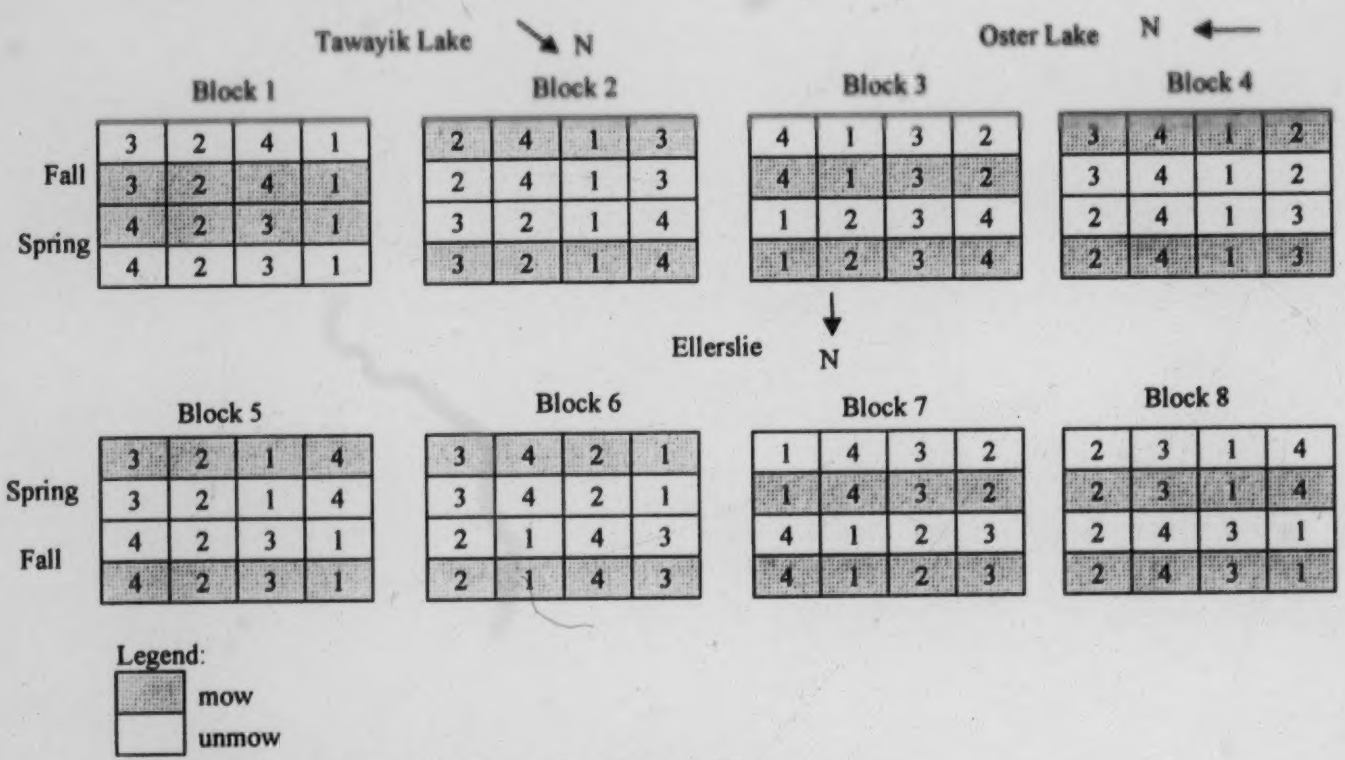
Scientific name	Common name
Cirsium arvense (L.) Scop.	Canada thistle
Taraxacum officinale Weber	Dandelion
Thlaspi arvense L.	Stinkweed

Figure 2.1. Map of plot layout at Ellerslie and Elk Island sites, 1998


Tawayik Lake
N
Oster Lake
N
Block 1
Block 2
Block 3
Block 4
Fall
Spring
3 2 4 1 | 2 4 1 3 | 4 1 3 2 | 3 4 1 2
3 2 4 1 | 2 4 1 3 | 4 1 3 2 | 3 4 1 2
4 2 3 1 | 3 2 1 4 | 1 2 3 4 | 2 4 1 3
Ellerslie
N
Block 5
Block 6
Block 7
Block 8
Spring
Fall
3 2 1 4 | 3 4 2 1 | 1 4 3 2 | 2 3 1 4
4 2 3 1 | 2 1 4 3 | 4 1 2 3 | 2 4 3 1
4 2 3 1 | 2 1 4 3 | 4 1 2 3 | 2 4 3 1
Legend:
mow
unmow

Plot length 12.6 m, plot width 8.84 m (map not to scale)

Figure 2.2. Map of plot layout at Ellerslie and Elk Island sites, 1999


Tawayik Lake
N
Oster Lake
N
Block 1
3 2 4 1
Fall
3 2 4 1
Spring
4 2 3 1
4 2 3 1
Block 2
2 4 1 3
2 4 1 3
3 2 1 4
3 2 1 4
Block 3
4 1 3 2
4 1 3 2
1 2 3 4
1 2 3 4
Block 4
3 4 1 2
3 4 1 2
2 4 1 3
2 4 1 3
Ellerslie
N
Block 5
3 2 1 4
Spring
3 2 1 4
Fall
4 2 3 1
4 2 3 1
Block 6
3 4 2 1
3 4 2 1
2 1 4 3
2 1 4 3
Block 7
1 4 3 2
1 4 3 2
4 1 2 3
4 1 2 3
Block 8
2 3 1 4
2 3 1 4
2 4 3 1
2 4 3 1
Legend:
mow
unmow

Plot length 12.6 m, plot width 8.84 m (map not to scale)

CHAPTER III. ROLE OF MOWING AND SEASON OF SEEDING IN NATIVE PLANT COMMUNITY DEVELOPMENT

1.0. INTRODUCTION

Revegetation seeding in temperate climates occurs in both spring and fall. The choice is often based on climatic limitations that restrict site access. However, consideration should also be given to life history strategies of seeded species to determine which season of seeding would provide more successful emergence, establishment and over-winter survivability.

The best time to seed is generally prior to the season with the most dependable precipitation (Hull 1948, Cook et al. 1974, Tainton 1981, Ries et al. 1987, Vallentine 1989), normally spring. Seeding at this time generally ensures suitable soil moisture for germination and seedling growth. However, most species in Alberta may also be seeded in late fall, as they can germinate at low temperatures (Kerr et al. 1993).

Late fall seeding breaks dormancy over winter and enables seedlings to establish early in the growing season and in sufficient number to fully exploit soil and water resources (Steppuhn et al. 1993), while taking advantage of a longer growing season (Romo and Lawrence 1990). Fall seeding should be conducted late enough that seeds will not germinate and grow before winter. A prolonged period of warm fall weather may induce germination, leaving plants vulnerable in subsequent cold weather. Seeding in spring avoids overwinter seed loss due to erosion and runoff. However, seeding is often delayed by wet conditions and because growth begins later in the season, environmental conditions such as drought often limit growth potential of young seedlings (Pearson 1994).

Numerous studies support fall seeding of cool season species. According to Cook et al. (1974), fall seeding is preferable for cool season grasses and legumes, assuming favorable soil moisture. Frischknect (1959) found fall seeded native and introduced grasses had faster growth and development than spring seeded. He attributed this in part to the ability of fall seeded grasses to begin growing earlier in spring. Steppuhn et al. (1993) found fall seeded kochia (*Kochia scoparia* L.) produced more forage than spring seeded, which developed later and had undersized root systems which could not fully utilize available water. Pearson (1994) found similar results, attributing increased productivity of fall seeded wheat to favorable temperature and moisture conditions during early spring growth. Hull (1948), McWilliams (1955), Douglas et al. (1960), Young et al. (1994) and Ries and Hofmann (1996) all reported higher productivity and/or greater seedling establishment with fall seeding of native and introduced cool season species.

In contrast, few studies support early spring seeding of cool season species. McGinnies (1960) found better establishment of introduced species with spring seeding. In tall grass revegetation studies in Manitoba, Morgan (1992) found spring seeding more successful than fall seeding. Kerr et al. (1993) preferred spring seeding because it enabled plants to take advantage of early spring moisture.

Kilcher (1961) cautioned that species react differently, therefore, fall or spring seeding should be explored for each species. For example, green needle grass (*Stipa viridula* Trin.) had higher productivity if fall seeded, while russian wild rye (*Elymus junceus* Fisch.) had a narrow range of acceptable spring seeding dates (Kilcher 1961). Ries and Hofmann (1996) found significant seeding date by year interactions due to environmental conditions at repeated seeding dates. They concluded the important factor in seeding is not season but weather and soil conditions that occur after seeding.

Even when seeding is conducted at the appropriate time, non-seeded species may significantly influence native plant community development. The facilitative contributions of annual species biomass to soil development and the establishment of ground cover to control soil erosion may be positive. However, non-seeded species, particularly perennials, may compete with seeded species for resources, limiting their establishment, growth and survivability. Mowing can control non-seeded species if conducted prior to seed set in annuals and prior to carbohydrate store replenishment in perennials (Pelech 1997). However, mowing too early can stimulate weed growth and seed head production (Leskiw 1978). Most published research focuses on the effect of mowing native vegetation, not on control of non-seeded species in native vegetation.

Gerling et al. (1995) found inflorescence density increased in response to mowing during the previous growing season. Daubenmire (1968) found increased inflorescence production after defoliation is a common phenomenon in grasses. Hesse and Salac (1972) found mowing delayed and extended the blooming period. The release of apical dominance translates into an increase in flower and, therefore, seed production. Increased seed production from non-seeded species could cause an increase in density the following year.

2.0. OBJECTIVES AND HYPOTHESES

2.1. Research Objectives

To compare the density, percent biovolume, density-biovolume and percent ground and canopy cover of selected native grasses and forbs and non-seeded species in:

- Fall versus spring seeded treatments.
- Mowed versus unmowed treatments.

2.2. Hypotheses

- Fall seeding will enable plants to take advantage of early spring moisture and a longer growing season, therefore, producing a higher density, percent biovolume, density-biovolume, canopy and ground cover of plants than spring seeding.
- Mowing will decrease canopy cover while increasing ground cover.

3.0. RESEARCH SITE DESCRIPTION AND EXPERIMENTAL DESIGN

3.1. Site Description

One research site is located at the University of Alberta Ellerslie Research Station, in southern Edmonton. Twp Elk Island National Park sites are located approximately 50 km east of Edmonton and separated from each other by a distance of approximately 3 km. All sites are in the Aspen Parkland ecoregion. For a more detailed description see Chapter 2.

The Aspen Parkland ecoregion has a subhumid to humid continental climate (Strong and Leggat 1992). Mean annual precipitation is 450 mm, 78% of which occurs as summer precipitation (Strong and Leggat 1992). The ecoregion is characterized by undulating to hummocky glacial till deposits (Crown 1977). Both sites are underlain by late Cretaceous bedrock of the Edmonton formation, a brackish water formation composed of sandy shales and bentonitic sandstone, clay and coal seams. The soil at the Ellerslie site is a Gleyed Black and Gleyed Eluviated Black Chernozem and is mapped as the Malmo soil series (Bowser et al. 1962). Oster Lake soil is a Dark Gray Luvisol and Tawayik Lake soil is a Dark Gray and Gleyed Dark Gray Luvisol (Hammermeister 1998). Moss (1955) described parkland as a mosaic of prairie patches and aspen groves, with prairie occupying the drier situations and aspen the more moist and sheltered places.

3.2. Experimental Design

There are four blocks at Ellerslie and two each at Oster and Tawayik Lakes (Figures 2.1 and 2.2). Each block is divided lengthwise into fall and spring seeded treatments. In 1998, the fall seeded treatment was split in half lengthwise (split plot design) into mowed and unmowed treatments. In 1999, both fall and spring seeded treatments were split in half lengthwise (split-split plot design) into mowed and unmowed treatments. Within each season and mowing treatment of each block are four seed mixes. Each plot is 12.6 m long and 8.84 m wide, and is bordered on all sides by a 1 m interplot area.

Four seed mixes of species common to the Aspen Parkland were used for this research (Table 2.1, Appendix A). The mixes were designed with equal amounts of pure live seed (PLS) of each species per vegetation type (grass or forb); grass-forb mixes were composed of 70% grasses and 30% forbs (Appendix B).

4.0. MATERIALS AND METHODS

4.1. Vegetation

Fall and spring seeded species were assessed in late July 1998, late May 1999 and late July 1999. Ten 0.1 m^2 quadrats were randomly located in each plot (five in mow, five in unmow). Quadrat number was determined by calculating the point at which the species curve reached a stable point, or the point where the number of species in each quadrat became constant (Braun-Blanquet 1932, Raunkiaer 1934).

The vegetation parameters assessed were: species plant density, percent biovolume, percent ground cover (live vegetation, litter, bare ground, moss) and percent live/dead canopy. Density was defined as the number of whole living plants and dead plants from the current growing season in a given area. Percent biovolume was the visual estimation of the volume of a species, as a percent of the total volume of vegetation in the quadrat. Percent ground cover was measured 1 cm above ground level. For this measurement, litter was defined as the previous year's growth. Percent live/dead canopy was determined by a visual estimate of the canopy when viewed from above.

4.2. Statistical Analyses

Density, percent biovolume, percent canopy and ground cover data were sorted by site (Tawayik Lake, Oster Lake, Ellerslie) and analyzed according to species grouping (seeded species, seeded grasses, seeded forbs, non-seeded species, non-seeded grasses, non-seeded forbs, total species). Density-biovolume was calculated by multiplying density by percent biovolume (per species per quadrat).

SAS for Windows V6.12 was the statistical software used. The mathematical models, including sample size and degrees of freedom, are described in Appendix C. The General Linear Model (GLM) was used to test for interaction and significance of main effects (season-mow and mix in 1998; season, mow and mix in 1999). Orthagonal contrasts were used where an interaction or effect was significant. Theoretically, a significant interaction of the main effects would preclude their independent examination. Orthagonal contrasts were conducted on main effects influenced by a significant interaction and results were discussed accordingly. A p-value of less than 0.05 is sufficient to reject the null hypothesis in each of the following analyses (Mapfumo 1999).

Species richness was analyzed using total number of species m^{-2}. A Wilcoxon signed rank test was used to determine differences between number of species seeded and number present in the plant community.

Post-hoc comparisons between years were conducted using the t-test for paired observations, where sample size was the same. No comparison could be conducted between years where sample size differed.

5.0. RESULTS

5.1. Interactions

In ecological field research, treatment effects are often difficult to separate (Givnish 1994, Huston 1997). Because natural processes tend not to act in isolation, interaction among treatments is expected. When interaction does occur, more than one treatment has likely influenced the result and, therefore, the result cannot be grouped with data unaffected by interaction. In this research interactions were extremely varied and lacked a common pattern, making them very difficult to summarize. Data affected by treatment effect interactions are clearly identified in Tables 3.1 to 3.19. In Appendix D tables contain values of significance for interaction between main effects and orthagonal contrasts for significant interactions. These tables should be consulted for interaction detail which cannot be easily summarized.

5.2. Fall Versus Spring Seeding

5.2.1. First growing season

The density, percent biovolume and density-biovolume of seeded grasses and forbs were higher and that of non-seeded grasses and forbs generally lower in spring than fall seeded treatments (Table 3.1, Figures 3.1 to 3.4). Spring unmow was significantly different from fall mow and fall unmow in 50% of the cases.

Seeded species densities were generally higher if seeded in spring than fall, especially for *Agropyron dasystachyum*, *A. trachycaulum*, *Koeleria macrantha*, *Stipa viridula* and *Vicia americana* (Table 3.2). Both *V. americana* and *Achillea millefolium* were present in the seedbank at all sites, causing overestimated counts.

Generally, non-seeded species densities, percent biovolumes and density-biovolumes were larger than those of seeded species (Table 3.1). Seeded forbs and non-seeded grasses were present but only as minor components of the community. The effect of season of seeding on seeded forbs and non-seeded grasses was generally small and differences between seasons were slight, compared to seeded grasses and non-seeded forbs. Tawayik tended to have the highest densities and density-biovolumes, especially for non-seeded species. Ellerslie tended to have the largest biovolumes and density-biovolumes, especially for seeded species and seeded grasses.

Spring seeding was consistently associated with higher species richness than fall seeding (Table 3.3). The number of grass species present in fall seeded treatments was significantly lower than the number of species seeded, but the difference was not statistically significant in the spring seeded treatments (Table 3.4).

Season of seeding did not consistently affect live vegetation or bare ground cover (Table 3.5). Live and dead canopy cover were higher in fall than spring seeded treatments and were statistically significant at Oster Lake and Ellerslie. There was no litter or moss present during the first growing season.

5.2.2. Early second growing season

The density of seeded grasses and forbs and the density-biovolume of seeded grasses were generally higher in spring than fall seeded treatments (Table 3.6). Percent biovolume of seeded grasses and forbs was not affected by season of seeding. The only emerging trend was that non-seeded forbs had a higher density in spring. Most species densities were higher in spring than fall seeded treatments, especially for *Agropyron trachycaulum* and *A. dasystachyum* (Table 3.7). Densities that were higher in fall than spring seeded treatments were usually forbs.

The general vegetation patterns remained similar to those of the first growing season (Table 3.6). Non-seeded species densities remained higher than those of seeded species. Although many of the seeded species were grasses, there was a significant increase in fall seeded forbs at Ellerslie. Most non-seeded species were forbs, although many annual species present in the first year had been replaced with perennial species.

Spring seeding remained consistently associated with higher species richness than fall seeding (Table 3.8). The number of grass and forb species in the plant communities of fall and spring seeded treatments was significantly less than the number of species seeded (Table 3.9).

Ground cover and percent dead canopy cover were not affected by season of seeding (Table 3.10). As in the first growing season, the fall treatment was associated with a higher percent live canopy.

Although not all trends from the first growing season were carried through to the early second growing season, the general success of spring seeding was still evident. Annual non-seeded species were no longer the most visually prominent; seeded grasses, with a few forbs and non-seeded species, were most prominent.

5.2.3. Late second growing season

Density, percent biovolume and density-biovolume of seeded grasses were higher in spring than fall seeded treatments (Table 3.11). Percent biovolume and density-biovolume of non-seeded forbs were higher in fall than spring seeded treatments. Differences in individual species densities between seasons were not as obvious as earlier in the growing season or the previous year (Table 3.12). Densities were similar between fall and spring seeded treatments, although some grasses had slightly higher densities in spring than fall seeded treatments. *Ratibida columnifera* was the only forb consistently affected by season of seeding with higher density in spring than fall seeding.

The general vegetation patterns remained similar to those from early in the second growing season (Table 3.11). Non-seeded species densities remained higher than those of seeded species. The general appearance of the vegetation reflected a more mature community; one with the promising presence of a variety of seeded grass and forb species and the less obtrusive presence of non-seeded species.

Spring seeding was consistently associated with higher species richness than fall seeding for grasses at all sites, but at only two sites for forbs (Table 3.13). The numbers of grass and forb species in plant communities of fall and spring seeded treatments remained significantly less than the number of species seeded (Table 3.14).

Neither season consistently affected ground or canopy cover, although live canopy was higher in fall than spring seeded treatments (Table 3.15). The only statistically significant difference occurred at Ellerslie, where fall seeded treatments had higher litter and moss, and lower bare ground than spring seeded treatments.

5.3. Mow Versus Unmow

5.3.1. First growing season

Non-seeded grass and forb densities were not affected by mowing (Table 3.1). Densities of grass species were generally higher in the mow than unmow treatment (Figure 3.5), especially *A. dasystachyum* and *A. trachycaulum* (Table 3.2). Several infrequently occurring forbs (*Ratibida columnifera, Solidago canadensis*) had higher densities in the unmow than mow treatment. Seeded grasses had higher biovolumes and density-biovolumes with mowing; non-seeded forbs had higher biovolumes without mowing (Figure 3.6). The mow treatment was usually associated with higher species richness than the unmow treatment (Table 3.3). The mow treatment was associated with a higher live vegetation cover and live canopy cover and the unmow treatment was associated with higher bare ground (Table 3.5).

5.3.2. Early second growing season

The emerging trend early in the second growing season was that the unmow treatment was associated with higher total species density than the mow treatment (Table 3.16). Another new trend was that non-seeded forbs had lower densities but higher density-biovolumes in the mow versus the unmow treatment. Compared to the first growing season, there was a significant increase in the density of non-seeded forbs at all sites in the fall mow treatment. Among sites, species performance was not consistent (Table 3.7). The two most common species, *Agropyron dasystachyum* and *A. trachycaulum*, were not affected by mowing.

General vegetation patterns remained similar to those of the first growing season (Table 3.16). The benefits of mowing observed in the first growing season decreased, evidenced by the significant increase in density of non-seeded forbs in the fall mow treatment. In both mow and unmow treatments, significantly fewer grasses were present in the vegetation community than were seeded (Table 3.8). The number of forbs was not affected by mowing (Table 3.9). Annual weed species were generally absent early in the second growing season. The importance of mowing was likely found not in measurements of plant species present, but in the absence of specific plant species. The mow treatment maintained a higher live canopy cover and lower bare ground and had a higher litter and lower dead canopy cover (Table 3.17).

5.3.3. Late second growing season

The effect of mowing late in the second growing season appears to be negligible. Mow was significantly different from the unmow treatment in less than 25% of the cases (Table 3.18). The percent biovolume data from Tawayik Lake was evidence of how close mean values for the mow and unmow treatments were. The two most common species, *Agropyron dasystachyum* and *A. trachycaulum*, did not have consistently higher densities in either mow or unmow treatment (Table 3.12). Mowing did not have an effect on species richness (Table 3.13). The numbers of grass and forb species present in mow and unmow plant communities remained significantly less than the number of species seeded (Table 3.14).

The mow treatment maintained a higher live canopy cover than the unmow treatment and was statistically significant at two sites (Table 3.19). Moss cover was higher in the mow than in the unmow treatment.

6.0. DISCUSSION

6.1. Fall Versus Spring Seeding

Many researchers consistently found suitable soil moisture conditions in early spring are critical to the success of fall seeding (Hull 1948, Cook et al. 1974, Belnap and Sharpe 1993, Steppuhn et al. 1993, Holt et al. 1994, Pearson 1994, Young et al. 1994, Ries and Hofman 1996). Steppuhn et al. (1993) found fall seeded species had sufficiently developed root systems to utilize available water and start growing earlier and faster than spring seeded species. This provides a longer growing season, making fall seeding more successful than spring seeding.

How then could this research have come to the opposite conclusion? The answer may lie in a study conducted by Ries and Hofmann (1996) which emphasized that although a given season (ie. fall) is expected to provide good establishment because of favorable temperatures and precipitation, failures may occur at any time when expected environmental conditions do not occur. Ries and Hoffman concluded that the important factor is not season, but weather and soil conditions after seeding.

Winter 1997, spring and summer 1998 were warmer and drier than the long term average (Chapter II). The necessary soil moisture conditions to give fall seeded species an early growth start were probably not present. The warm, dry conditions in early spring likely negated the moisture advantage usually associated with fall seeding, thus preventing early growth and extension of the growing season.

Spring seeded species may have started to grow when soil moisture was more abundant and, therefore, may have foregone a period of growth limitation, enabling them to achieve better seeding success than fall seeded species. It is unlikely cultivation prior to spring seeding affected the growth of spring seeded species as no first growing season data indicate non-seeded species density or percent biovolume were consistently lower in spring seeded treatments. The spring seeded treatment was consistently associated with higher species richness than the fall seeded treatment, further confirming the success of spring seeding.

In the second growing season there were fewer cases of statistical significance, deviations in values were not as large and mean values were more similar, compared to the first growing season. This likely indicates the decreasing influence of management techniques and the subsequent increasing influence of biotic and abiotic components (eg. Gleason 1917) and plant community development processes, particularly succession.

Steppuhn et al. (1993) found results were not all consistent among years. Bement et al. (1965) found results varied between years because of moisture. This is a likely explanation in our study as summer 1998 was warmer and drier than the long term average, while summer 1999 was cooler and wetter (Chapter II). McGinnies (1973) and Ries and Hofmann (1996) also recognized environmental variation among years in their research.

The influences of moisture and temperature may be part of a larger influence of competition and succession. The initial influence of seeding season decreased gradually over the second growing season which may be explained by Pickett's (1976) view of succession as a gradient of competition emphasizing life history and physiological characteristics. The influence of seeding season may be most important during the first growing season and over-winter period when establishment and survival were critical. Beyond the early second growing season, seeding season appears to be a minor influence, compared to successional and competitive processes.

6.2. Mowing

Timing of mowing native vegetation is critical to achieve desired results (Pelech 1997). The lack of statistical significance between the mow and unmow treatments may be due to either the timing of mowing or the time lag between mowing and the vegetation assessment. Willson and Stubbendieck (1996) associated the lack of significance to uneven ground surface in the plots and mowing above the majority of tiller growing points. However, despite the lack of statistical significance, mowing may indeed have biological significance. According to Facelli and Pickett (1991), litter affects the structure and function of the native plant community through its physical and chemical impacts.

During the first growing season, seeded grasses benefited from mowing. Because mowed material was not removed, there was an increase in ground cover in mowed treatments. Mowing contributes litter, which increases germination and establishment of seeded species by prolonging the availability of moisture (Glendening 1942). Later development processes, including the formation of adventitious roots and tillering, are also dependent on available soil moisture and may have benefited from the presence of litter (Glendening 1942). Willms et al. (1993) attributed increased biomass production to reduced evaporation and increased water availability under litter cover. Moldy soil was observed in several plots in this study indicating high moisture levels under litter (unmeasured observation).

Although mowing did not consistently reduce first growing season non-seeded forb density or density-biovolume, it did reduce biovolume, and thus, plant size. According to Mueggler (1972), smaller potential competitors (non-seeded forbs) equals less competition for seeded species, for any number of factors including light, nutrients and water.

Weaver and Roland (1952) found plant litter reduced species diversity in the plant community, by reducing soil temperature. A similar effect of litter cannot be reported in this research, as mowing (which produces litter) increased species richness (a component of species diversity) at most sites.

Mueggler (1972) attributed increased production the year following mowing to decreased competition from surrounding vegetation. It is difficult to accept or reject the validity of Mueggler's finding to this research as competition was not measured and it would have been difficult to visually estimate.

Drake (1991) found competitive interactions occur during community development and can lead to differences in community structure. Evidence in this research is the dominance of annual non-seeded species in the first growing season yielding to seeded species and perennial non-seeded species in the second growing season. Annual species play an important role in facilitative contributions of biomass to soil development and the establishment of ground cover to control soil erosion. This resembles the facilitative process of succession (Clements 1916) where one species prepares the way for the next. The replacement of non-seeded annual species with seeded species and perennial non-seeded species may be explained by Pickett's (1976) view of succession as a gradient of competition emphasizing life history and physiological characteristics. After the critical stages of establishment and over-winter survival, the seeded species were better able to compete against the non-seeded species. Hence, the influence of mowing season was most important during the first growing season and over-winter period when establishment and survival were critical. Beyond the early second growing season, mowing appears to be a minor influence, compared to successional and competitive processes.

7.0. MANAGEMENT IMPLICATIONS

7.1. Fall Versus Spring Seeding

Seeding in the spring will improve the likelihood of successful seeded native plant community development in the Aspen Parkland, especially during unusually warm, dry years. However, the choice of seeding season should also consider potential site access restrictions that may occur during a wet spring. Consideration should also be given to the life history strategies of the specific species that will be seeded, to determine which season of seeding would likely provide the greatest chance of successful emergence, establishment and over-winter survivability.

7.2. Mow Versus Unmow

Mowing will increase seeded species success, while reducing biovolume of potential competitors, during the first growing season. Mowing has no visible or measurable influence beyond the early part of the second growing season.

Annual species likely do not have the long-term competitive effects that most perennial species do. Furthermore, these non-seeded species play a vital role providing ground cover and aiding in nutrient cycling during the initial years of native plant community development.

Mowing should be conducted just before annuals seed set and perennials replenish carbohydrate stores. Mowing too early may stimulate the growth of non-seeded species, while mowing too late may have no effect on non-seeded species. Accessing remote sites with a mower may be expensive or unfeasible. The decision whether or not to mow relies heavily on the ability of the manager to compare financial costs to the perceived benefits of mowing. If the decision is made to mow, good management is essential to ensure suitable timing and mowing height.

8.0. CONCLUSIONS

8.1. Fall Versus Spring Seeding

- Densities of seeded grasses were higher in spring than fall seeded treatments.
- Densities of seeded forbs were higher in spring than fall seeded treatments during the first and early second growing seasons but the difference disappeared by the end of the second growing season.
- Densities of non-seeded grasses and forbs were lower in spring than fall seeded treatments in the first growing season. Early in the second growing season, non-seeded species densities were higher in spring seeded treatments. The trend disappeared by late in the second growing season.
- Biovolumes of seeded grasses were higher in spring than fall seeded treatments during the first and late second growing seasons. There was no trend early in the second growing season.
- Biovolumes of seeded forbs were higher in spring than fall seeded treatments during the first growing season but the difference disappeared by the second growing season.
- Biovolumes of non-seeded grasses and forbs were lower in spring than fall seeded treatments during the first and early second growing seasons. Late in the second growing season, non-seeded forb biovolume remained lower in spring but non-seeded grass biovolumes were no longer affected by seeding season.
- Density-biovolumes of seeded grasses were higher in spring than fall.
- Density-biovolumes of seeded forbs were higher in spring than fall seeded treatments during the first growing season but the difference disappeared by the second growing season.

- Density-biovolumes of non-seeded grasses and forbs were lower in spring than fall seeded treatments during the first and early second growing seasons. Late in the second growing season, non-seeded forb density-biovolume remained lower in spring but non-seeded grass density-biovolumes were no longer affected by seeding season.
- Fall seeding was consistently associated with higher live canopy cover than spring seeding during the two growing seasons. Other ground cover or canopy cover parameters were not affected by seeding season.

8.2. Mow Versus Unmow

- Densities of seeded grasses were higher in the mowed than unmowed treatments during the first growing season. Mowing had no effect on seeded grass density beyond the first growing season and did not affect seeded forb density during the two growing seasons.
- Densities of non-seeded grasses and forbs were not affected by mowing in the first growing season. Non-seeded forb density was lower in the mowed treatment early in the second growing season. Mowing had no effect on non-seeded species density beyond the early part of the second growing season.
- Biovolumes of seeded grasses were higher in mowed than unmowed treatments in the first growing season. Seeded forb biovolumes were not affected by mowing during the two growing seasons and seeded grass biovolumes were not affected by mowing during the second growing season.
- Biovolumes of non-seeded forbs were higher without mowing in the first growing season but were not affected by mowing during the second growing season. Non-seeded grass biovolumes were not affected by mowing during the two growing seasons.
- Density-biovolumes of seeded grasses were higher with mowing during the first growing season; mowing had no effect on seeded grass density-biovolume beyond the first growing season. Density-biovolumes of seeded forbs were not affected by mowing during the first two growing seasons.

- Density-biovolumes of non-seeded species were not affected by mowing during the first growing season. Density-biovolumes of non-seeded forbs were higher with mowing during the early second growing season; non-seeded grass density-biovolumes were not affected by mowing during the second growing season.
- Live vegetation cover and live canopy cover were higher in the mowed treatment and bare ground was higher in the unmowed treatment during the first growing season. Early in the second growing season, the mow treatment maintained a higher live canopy cover and lower bare ground and had a higher litter and lower dead canopy cover. Late in the second growing season, the mow treatment maintained a higher live canopy cover and moss cover.

8.3. Summary

Generally density, percent biovolume and density-biovolume of seeded grasses and forbs were higher, and that of non-seeded species lower, in spring than fall seeded treatments. Ground and canopy cover were not affected by seeding season. Mowing increased seeded plant density, biovolume and density-biovolume during the first growing season but not the second. Mowing decreased non-seeded species biovolume during the first and density early in the second growing season. Mowing decreased bare ground in the first and early in the second growing seasons.

9.0. LITERATURE CITED

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Table 3.1. Mean density, biovolume and density-biovolume of species in season-mow treatments in July 1998 at Ellerslie and Tawayik Lake and Oster Lake, Elk Island National Park

	Density (plants m^{-2})			% Biovolume			Density-Biovolume		
Species Summation	Fall Mow	Fall Unmow	Spring Unmow	Fall Mow	Fall Unmow	Spring Unmow	Fall Mow	Fall Unmow	Spring Unmow
Tawayik Lake									
All species	289 [1]	334	356						
	132 [2]	160	154						
Seeded species	18	11	44	3 c	1 b	16 a	4 b	2 b	37 a
	15	14	32	2	1	17	5	3	58
Seeded grasses	13	7	29	2 b	1 b	14 a	3 b	1 b	35 a
	13	9	22	2	1	17	5	3	58
Seeded forbs	5	4	15	1	0	1	1	0	2
	8	10	21	1	1	3	2	1	4
Non-seeded species	271	323	313	98 a	99 a	84 b	1312 a	1749 a	1070 b
	132	158	155	2	1	17	994	1684	1118
Non-seeded grasses	6	83	21	0 b	0 b	3 a	1	1	12
	13	14	27	1	1	8	3	1	59
Non-seeded forbs	265	315	292	97 b	98 b	82 a	1311 a	1748 a	1057 b
	127	159	149	3	2	19	994	1685	1124
Oster Lake									
All species	142	109	130						
	97	36	59						
Seeded species	26	11	28	6 b	3 b	20 a	8 a	4 a	39 b
	82	13	28	7	4	23	14	12	62
Seeded grasses	10	5	13	4 b	2 b	16 a	5 a	1 a	28 b
	13	8	13	5	3	21	10	4	53
Seeded forbs	16	7	15	2	2	4	3	3	11
	79	12	22	5	4	7	10	12	26

Table 3.1. Mean density, biovolume and density-biovolume of species in season-mow treatments in July 1998 at Ellerslie and Tawayik Lake and Oster Lake, Elk Island National Park (cont'd)

	Density (plants m^{-2})			% Biovolume			Density-Biovolume		
Species Summation	Fall Mow	Fall Unmow	Spring Unmow	Fall Mow	Fall Unmow	Spring Unmow	Fall Mow	Fall Unmow	Spring Unmow
Oster Lake (cont'd)									
Non-seeded species	117	98	102	94 a	97 a	80 b	292	291	232
	42	34	53	7	4	23	216	151	217
Non-seeded grasses	1	1	2	0	0	1	0	0	1
	6	4	7	0	2	5	0	0	10
Non-seeded forbs	115	97	100	94 a	96 a	80 b	292	291	230
	42	34	51	7	5	23	216	151	217
Ellerslie									
All species	83	72	63						
	44	39	56						
Seeded species	19 b	14 b	22 a	25 b	20 b	50 a	46 b	39 b	108 a
	16	16	17	25	27	39	76	65	121
Seeded grasses	15 b	12 b	18 a	23 b	18 b	48 a	43 b	36 b	105 a
	14	13	16	23	26	39	75	65	122
Seeded forbs	3	2	3	2	3	3	3	3	4
	7	7	7	11	9	12	13	12	14
Non-seeded species	64	58	41	75 a	80 a	48 b	163 a	139 a	102 b
	43	36	52	25	27	39	180	109	171
Non-seeded grasses	18	21	31	1	3	2	1	3	6
	55	47	70	2	12	13	2	22	40
Non-seeded forbs	63 a	56 a	38 b	74 a	77 a	46 b	163 a	136 a	96 b
	42	36	52	25	29	39	180	110	169

[1] Mean, [2] Standard Deviation

Values in a row sharing same letter are not significantly different at $\alpha=0.05$

Fill colour indicates values affected by season-mow*mix interaction

Table 3.2. Mean density (plants m^{-2}) of seeded species in three treatments in July 1998

	Season		Mowing		Mix					
Species	Fall	Spring	Mow	Unmow	1	2	3	4	Mean	SD
Tawayik Lake										
Agropyron dasystachyum	0	5	1	2	2	2	2	2	2.6	5.9
Agrostis stolonifera	0	0	0	0	0	0	0	0	0.0	0.0
Agropyron trachycaulum	8	17	11	11	12	10	11	12	12.4	13.1
Bouteloua gracilis	0	0	0	0	0	0	0	0	0.1	0.8
Bromus carinatus	0	0	0	0	0	0	0	0	0.0	0.0
Festuca hallii	0	1	0	1	0	2	0	0	0.6	2.9
Festuca ovina	0	0	0	0	0	0	0	0	0.0	0.0
Koeleria macrantha	0	1	0	0	0	1	0	0	0.3	2.1
Poa palustris	0	2	0	1	0	3	0	0	0.9	5.7
Stipa viridula	1	4	1	2	4	2	1	1	2.3	5.8
Achillea millefolium	1	3	2	2	1	1	3	1	1.9	5.6
Aster laevis	0	0	0	0	0	0	0	0	0.0	0.0
Gaillardia aristata	0	0	0	0	0	0	0	0	0.1	1.1
Linum lewisii	0	0	0	0	0	0	0	1	0.3	1.9
Monarda fistulosa	0	0	0	0	0	0	0	0	0.1	1.6
Petalostemon purpureum	0	0	0	0	0	0	0	0	0.1	0.8
Ratibida columnifera	0	0	0	0	0	0	0	0	0.1	0.8
Solidago canadensis	0	0	0	0	0	0	0	0	0.0	0.0
Solidago missouriensis	0	0	0	0	0	0	0	0	0.0	0.0
Vicia americana	3	7	2	5	5	5	2	4	4.8	9.4
Unidentified forb	1	4	1	2	2	6	0	0	2.4	12.6
Oster Lake										
Agropyron dasystachyum	1	2	2	1	2	1	2	1	1.6	4.1
Agrostis stolonifera	0	0	0	0	0	0	0	0	0.1	0.8
Agropyron trachycaulum	6	9	1	7	6	5	8	8	7.4	9.9
Bouteloua gracilis	0	0	0	0	0	0	0	0	0.1	0.8
Bromus carinatus	0	0	0	0	0	0	0	0	0.0	0.0
Festuca hallii	0	0	0	0	0	1	0	0	0.1	1.1
Festuca ovina	0	0	0	0	0	0	0	0	0.0	0.0
Koeleria macrantha	0	0	0	0	0	0	0	0	0.0	0.0
Poa palustris	0	0	0	0	0	0	0	0	0.2	1.4
Stipa viridula	1	1	1	1	1	0	1	0	0.7	2.5
Achillea millefolium	3	4	2	4	2	2	2	6	3.3	8.7
Aster laevis	0	1	0	0	0	0	1	0	0.4	2.5
Gaillardia aristata	0	1	0	1	0	0	2	0	0.7	4.4
Linum lewisii	0	1	0	0	0	0	1	1	0.4	2.3
Monarda fistulosa	0	0	0	0	0	0	0	0	0.1	0.8
Petalostemon purpureum	0	0	0	0	0	0	0	0	0.1	0.8
Ratibida columnifera	0	0	0	0	0	0	0	0	0.1	0.8
Solidago canadensis	0	0	0	0	0	0	0	0	0.1	1.1
Solidago missouriensis	0	0	0	0	0	0	0	0	0.1	1.1
Vicia americana	0	2	0	1	2	0	1	0	1.0	4.1
Unidentified forb	7	7	14	4	0	1	21	6	7.0	41.7

Table 3.2. Mean density (plants m^{-2}) of seeded species in three treatments in July 1998 (cont'd)

	Season		Mowing		Mix					
Species	Fall	Spring	Mow	Unmow	1	2	3	4	Mean	SD
Ellerslie										
Agropyron dasystachyum	1	2	2	1	1	1	2	2	1.7	4.5
Agrostis stolonifera	0	0	0	0	0	0	0	0	0.0	0.0
Agropyron trachycaulum	11	14	12	12	17	8	13	10	12.6	13.6
Bouteloua gracilis	0	0	0	0	0	0	0	0	0.0	0.6
Bromus carinatus	0	0	0	0	0	0	0	0	0.0	0.0
Festuca hallii	0	1	0	0	0	1	0	0	0.3	2.0
Festuca ovina	0	0	0	0	0	0	0	0	0.0	0.0
Koeleria macrantha	0	0	0	0	0	0	0	0	0.3	1.8
Poa palustris	0	0	1	0	0	1	0	1	0.3	2.2
Stipa viridula	1	1	1	1	1	1	1	0	0.8	3.1
Achillea millefolium	0	0	1	0	0	0	1	0	0.2	1.7
Aster laevis	0	0	0	0	0	0	0	1	0.1	1.2
Gaillardia aristata	0	1	0	1	0	0	1	2	0.7	3.1
Linum lewisii	0	0	1	0	0	0	1	1	0.2	1.4
Monarda fistulosa	0	0	0	0	0	0	0	0	0.1	0.8
Petalostemon purpureum	0	0	0	0	0	0	0	0	0.1	1.1
Ratibida columnifera	0	0	0	0	0	0	0	0	0.0	0.0
Solidago canadensis	0	0	0	0	0	0	1	0	0.1	1.2
Solidago missouriensis	0	0	0	0	0	0	0	0	0.0	0.6
Vicia americana	1	0	2	1	0	0	1	3	0.8	4.0
Unidentified forb	0	1	0	1	0	0	1	1	0.7	3.2

Table 3.3. Species richness (number of species per m^2) in twelve treatments in July 1998 Ellerslie and Tawayik Lake and Oster Lake, Elk Island National Park

	Fall Mow				Fall Unmow				Spring Unmow						
Site/Species	Mix 1	Mix 2	Mix 3	Mix 4	Mix 1	Mix 2	Mix 3	Mix 4	Mix 1	Mix 2	Mix 3	Mix 4	Mean	SD	Summation[1]
Tawayik Lake															
Grasses present	3	3	3	1	2	1	1	1	3	6	5	3	2.7	1.6	5.3
Grasses seeded	6	10	6	10	6	10	6	10	6	10	6	10	8.0		
Forbs present	2	2	2	2	3	1	2	2	2	3	7	3	2.6	1.5	
Forbs seeded	0	0	10	10	0	0	10	10	0	0	10	10	5.0		
Oster Lake															
Grasses present	3	4	3	3	2	1	2	1	3	4	3	4	2.8	1.1	5.6
Grasses seeded	6	10	6	10	6	10	6	10	6	10	6	10	8.0		
Forbs present	0	1	4	1	1	2	4	2	2	3	8	6	2.8	2.3	
Forbs seeded	0	0	10	10	0	0	10	10	0	0	10	10	5.0		
Ellerslie															
Grasses present	3	5	3	4	2	2	3	4	4	6	4	5	3.8	1.2	5.9
Grasses seeded	6	10	6	10	6	10	6	10	6	10	6	10	8.0		
Forbs present	0	0	5	2	0	0	2	5	0	0	6	6	2.2	2.6	
Forbs seeded	0	0	10	10	0	0	10	10	0	0	10	10	5.0		

[1] Value is the summation of means for grasses present and forbs present

Table 3.4. Wilcoxon z-score for species richness (number of species per m^2) of grasses and forbs seeded versus present in July 1998 at Ellerslie and Tawayik Lake and Oster Lake, Elk Island National Park

Site	Season mow	Mix	Grasses seeded versus present	Forbs seeded versus present
Ellerslie			0.0001*	0.2757
Oster			0.0001*	0.8827
Tawayik			0.0001*	1.0000
Ellerlsie	Fall mow		0.0275*	0.6423
	Fall unmow		0.0275*	0.6423
	Spring unmow		0.0515	0.6400
Oster	Fall mow		0.0247*	0.8809
	Fall unmow		0.0265*	1.0000
	Spring unmow		0.0265*	1.0000
Tawayik	Fall mow		0.0247*	1.0000
	Fall unmow		0.0247*	1.0000
	Spring unmow		0.0515	1.0000
Ellerslie		1	0.0636	1.0000
		2	0.0636	1.0000
		3	0.0593	0.0636
		4	0.0593	0.0636
Oster		1	0.0593	0.1967
		2	0.0593	0.0636
		3	0.0593	0.0593
		4	0.0636	0.0636
Tawayik		1	0.0593	0.0593
		2	0.0636	0.0636
		3	0.0636	0.0593
		4	0.0593	0.0593

* indicates value significant at α=0.05

Table 3.5 Mean percent ground and canopy cover in season-mow treatments in July 1998 at Ellerslie and Tawayik Lake and Oster Lake, Elk Island National Park

Parameter	Fall Mow	Fall Unmow	Spring Unmow
Tawayik Lake			
% Live vegetation	7.5[1]	4.8	8.0
	9.1[2]	2.7	10.8
% Bare ground	92.5	95.2	92.0
	9.1	2.7	10.8
% Live canopy	95.2	91.3	82.6
	8.1	20.4	19.4
% Dead canopy	1.9	5.5	0.4
	5.8	18.2	1.8
Oster Lake			
% Live vegetation	5.4	2.7	4.6
	3.7	1.3	3.0
% Bare ground	94.6	97.3	95.4
	3.7	1.3	3.1
% Live canopy	85.4 a	81.3 a	53.7 b
	18.8	19.3	30.5
% Dead canopy	0.3	0.6	0.2
	0.6	1.7	1.2
Ellerslie			
% Live vegetation	2.9	2.8	2.1
	2.0	2.2	1.6
% Bare ground	97.0	97.0	97.9
	2.1	2.6	1.6
% Live canopy	36.1 a	32.2 a	8.1 b
	25.8	19.7	7.7
% Dead canopy	13.3	10.3	0.2
	13.0	9.5	0.9

[1] Mean, [2] Standard Deviation

Values in a row sharing same letter are not significantly different at $\alpha=0.05$

Fill colour indicates values affected by season-mow*mix interaction

Table 3.6. Mean density, biovolume and density-biovolume of species in season treatments in May 1999 at Ellerslie and Tawayik Lake and Oster Lake, Elk Island National Park

Species Summation	Density (plants m^{-2}) Fall	Density (plants m^{-2}) Spring	% Biovolume Fall	% Biovolume Spring	Density-Biovolume Fall	Density-Biovolume Spring
Tawayik Lake						
All species	459 [1]	721				
	250 [2]	288				
Seeded species	17	45	14	46	30	153
	16	53	19	26	46	284
Seeded grasses	13	38	13	45	27	150
	14	50	18	26	45	284
Seeded forbs	4	8	1	1	2	3
	10	14	3	5	12	17
Non-seeded species	442	676	87	54	971	599
	250	282	18	26	548	612
Non-seeded grasses	16	65	2	3	4 b	17 a
	24	98	7	4	10	38
Non-seeded forbs	426	611	84	51	967	583
	245	250	19	26	550	610
Oster Lake						
All species	293	429				
	217	272				
Seeded species	25	36	38	53	75	107
	21	22	27	26	74	87
Seeded grasses	16	27	30	45	54	88
	12	18	27	27	63	80
Seeded forbs	9	9	9	8	22	18
	17	14	17	16	54	49
Non-seeded species	268	393	62	47	478	288
	216	272	27	26	768	344
Non-seeded grasses	5	12	2	3	6	6
	13	18	7	6	22	18
Non-seeded forbs	263	381	59	44	472	282
	218	268	26	25	769	344
Ellerslie						
All species	488	520				
	247	225				
Seeded species	36	36	72	70	152	161
	33	26	28	29	245	136
Seeded grasses	27	28	67	66	144	152
	30	21	29	30	247	138
Seeded forbs	9	8	5	4	8	9
	16	17	12	11	22	26
Non-seeded species	452	484	28	30	148	206
	247	225	28	29	167	415
Non-seeded grasses	101	62	5	4	27	18
	139	102	12	12	65	45
Non-seeded forbs	351	419	23	26	121	188
	176	216	25	27	155	414

[1] Mean, [2] Standard Deviation
Values in a row sharing same letter are not significantly different at α=0.05
Fill colour indicates values affected by one or more two and three-way interactions

Table 3.7. Mean density (plants m^{-2}) of seeded species in three treatments in May 1999

	Season		Mowing		Mix					
Species	Fall	Spring	Mow	Unmow	1	2	3	4	Mean	SD
Tawayik Lake										
Agropyron dasystachyum	1	6	4	3	3	5	5	1	3.4	5.0
Agrostis stolonifera	0	0	0	0	0	0	0	0	0.0	0.0
Agropyron trachycaulum	12	26	25	14	23	20	14	20	19.1	12.1
Bouteloua gracilis	0	0	0	0	0	0	0	0	0.0	0.0
Bromus carinatus	0	0	0	0	0	0	0	0	0.0	0.0
Festuca hallii	0	1	1	0	0	2	0	1	0.6	1.5
Festuca ovina	0	0	0	0	0	0	0	0	0.0	0.0
Koeleria macrantha	0	0	0	0	0	0	0	0	0.0	0.0
Poa palustris	1	3	3	1	0	3	2	3	1.8	2.4
Stipa viridula	0	1	0	1	1	1	1	0	0.6	1.0
Achillea millefolium	3	3	3	2	1	2	4	5	2.8	2.6
Aster laevis	0	0	0	0	0	0	0	0	0.1	0.3
Gaillardia aristata	0	0	0	0	0	0	0	0	0.0	0.0
Linum lewisii	0	0	0	0	0	0	0	0	0.0	0.0
Monarda fistulosa	0	0	0	0	0	0	1	0	0.1	0.5
Petalostemon purpureum	0	0	0	0	0	0	0	0	0.0	0.0
Ratibida columnifera	0	0	0	0	0	0	0	0	0.0	0.0
Solidago canadensis	0	0	0	0	0	0	0	0	0.0	0.0
Solidago missouriensis	0	0	0	0	0	0	0	0	0.1	0.5
Vicia americana	1	5	3	3	3	1	3	4	2.8	2.5
Unidentified forb	0	0	0	0	0	0	0	0	0.0	0.0
Oster Lake										
Agropyron dasystachyum	3	6	5	4	5	3	7	3	4.5	3.0
Agrostis stolonifera	0	0	0	0	0	0	0	0	0.0	0.0
Agropyron trachycaulum	12	14	13	14	17	12	12	13	13.2	5.0
Bouteloua gracilis	0	0	0	0	0	0	0	0	0.0	0.0
Bromus carinatus	0	0	0	0	0	0	0	0	0.0	0.0
Festuca hallii	0	2	1	1	0	2	0	1	0.8	1.4
Festuca ovina	0	0	0	0	0	0	0	0	0.0	0.0
Koeleria macrantha	0	0	0	0	0	0	0	0	0.0	0.0
Poa palustris	0	5	3	2	2	3	2	4	2.5	3.1
Stipa viridula	0	1	1	0	0	0	1	1	0.4	0.7
Achillea millefolium	8	6	7	8	4	8	7	10	7.2	5.6
Aster laevis	0	0	0	0	0	1	1	0	0.3	0.9
Gaillardia aristata	0	0	0	0	0	0	1	0	0.1	0.3
Linum lewisii	0	1	0	1	0	0	2	0	0.4	1.0
Monarda fistulosa	0	0	0	0	0	0	0	0	0.1	0.3
Petalostemon purpureum	0	0	0	0	0	0	0	0	0.0	0.0
Ratibida columnifera	0	0	0	0	0	0	0	0	0.1	0.3
Solidago canadensis	0	0	1	0	0	0	1	0	0.3	0.6
Solidago missouriensis	0	0	0	0	0	0	0	0	0.0	0.0
Vicia americana	1	1	1	1	1	0	0	1	0.6	0.9
Unidentified forb	0	0	0	0	0	0	0	0	0.0	0.0

Table 3.7. Mean density (plants m^{-2}) of seeded species in three treatments in May 1999 (cont'd)

	Season		Mowing		Mix					
Species	Fall	Spring	Mow	Unmow	1	2	3	4	Mean	SD
Ellerslie										
Agropyron dasystachyum	3	5	3	5	4	3	4	4	3.8	2.3
Agrostis stolonifera	0	1	0	0	0	1	0	1	0.3	0.6
Agropyron trachycaulum	17	18	15	20	24	15	16	16	17.7	6.8
Bouteloua gracilis	0	0	0	0	0	0	0	0	0.0	0.1
Bromus carinatus	0	0	0	0	0	0	0	0	0.0	0.0
Festuca hallii	1	1	1	1	0	2	0	1	0.8	0.9
Festuca ovina	0	0	0	0	0	0	0	0	0.1	0.2
Koeleria macrantha	0	1	1	0	0	2	0	0	0.5	1.3
Poa palustris	5	1	3	3	3	4	1	3	2.8	3.0
Stipa viridula	1	2	1	1	1	1	2	1	1.4	1.1
Achillea millefolium	1	2	2	1	0	0	3	3	1.5	2.0
Aster laevis	0	0	0	1	0	0	1	1	0.4	0.6
Gaillardia aristata	0	0	1	0	0	0	1	1	0.4	0.6
Linum lewisii	1	1	1	1	0	0	2	1	0.7	0.8
Monarda fistulosa	1	0	0	1	0	0	2	0	0.5	1.8
Petalostemon purpureum	0	0	0	0	0	0	0	0	0.0	0.0
Ratibida columnifera	0	1	1	0	0	0	2	0	0.4	1.3
Solidago canadensis	0	0	0	0	0	0	0	1	0.3	0.8
Solidago missouriensis	0	0	0	0	0	0	1	0	0.3	0.5
Vicia americana	5	3	4	4	0	0	6	10	4.0	4.8
Unidentified forb	0	0	0	0	0	0	1	0	0.2	0.6

Table 3.8. Species richness (number of species per m^2) in twelve treatments in May 1999 Ellerslie and Tawayik Lake and Oster Lake, Elk Island National Park

	Fall Mow				Fall Unmow				Spring Mow				Spring Unmow						
Site/Species	Mix	Mix 2	Mix 3	Mix	Mix 1	Mix 2	Mix 3	Mix 4	Mix 1	Mix 2	Mix 3	Mix 4	Mix 1	Mix 2	Mix 3	Mix 4	Mean	SD	Summation[1]
Tawayik Lake																			4.5
Grasses present	1	2	1	3	1	2	1	2	4	5	3	4	3	5	4	3	2.8	1.4	
Grasses seeded	6	10	6	10	6	10	6	10	6	10	6	10	6	10	6	10	8.0		
Forbs present	1	1	2	2	0	2	2	2	1	1	2	2	3	2	3	2	1.8	0.8	
Forbs seeded	0	0	10	10	0	0	10	10	0	0	10	10	0	0	10	10	5.0		
Oster Lake																			5.0
Grasses present	2	3	3	3	2	2	3	1	3	4	4	4	3	4	3	5	3.1	1.0	
Grasses seeded	6	10	6	10	6	10	6	10	6	10	6	10	6	10	6	10	8.0		
Forbs present	1	2	1	2	0	2	3	1	2	1	5	2	2	0	4	3	1.9	1.3	
Forbs seeded	0	0	10	10	0	0	10	10	0	0	10	10	0	0	10	10	5.0		
Ellerslie																			8.1
Grasses present	5	5	4	4	6	5	5	4	3	9	3	7	3	7	4	6	5.0	1.7	
Grasses seeded	6	10	6	10	6	10	6	10	6	10	6	10	6	10	6	10	8.0		
Forbs present	0	0	6	6	0	1	6	5	1	0	6	8	0	0	6	5	3.1	3.1	
Forbs seeded	0	0	10	10	0	0	10	10	0	0	10	10	0	0	10	10	5.0		

[1] Value is the summation of means for grasses present and forbs present

Table 3.9. Wilcoxon z-score for species richness (number of species per m^2) of grasses and forbs seeded versus present in May 1999 at Ellerslie and Tawayik Lake and Oster Lake, Elk Island National Park

Site	Season	Mow	Mix	Grasses seeded versus present	Forbs seeded versus present
Ellerslie				0.0002*	0.3498
Oster				0.0001*	0.7713
Tawayik				0.0001*	0.8917
Ellerlsie	Fall			0.0014*	0.5420
	Spring			0.0592	0.5429
Oster	Fall			0.0007*	0.8712
	Spring			0.0007*	0.8716
Tawayik	Fall			0.0007*	0.8699
	Spring			0.0007*	1.0000
Ellerlsie		Mow		0.0120*	0.5420
		Unmow		0.0105*	0.5426
Oster		Mow		0.0007*	1.0000
		Unmow		0.0007*	0.7032
Tawayik		Mow		0.0008*	1.0000
		Unmow		0.0008*	0.8699
Ellerslie			1	0.0668	0.4533
			2	0.0202*	0.4533
			3	0.0202*	0.0131*
			4	0.0202*	0.0202*
Oster			1	0.0194*	0.0688
			2	0.0202*	0.0668
			3	0.0177*	0.0211*
			4	0.0211*	0.0202*
Tawayik			1	0.0202*	0.0688
			2	0.0194*	0.0194*
			3	0.0202*	0.0177*
			4	0.0202*	0.0131*

* indicates value significant at α=0.05

Table 3.10. Mean percent ground and canopy cover in season treatments in May 1999 at Ellerslie and Tawayik Lake and Oster Lake, Elk Island National Park

Parameter	Fall	Spring
Tawayik Lake		
% Live vegetation	33.6 [1]	40.7
	22.5 [2]	27.3
% Litter	23.4	35.3
	25.8	25.1
% Bare ground	42.7	23.1
	24.6	21.8
% Moss	0.3	0.9
	1.1	3.5
% Live canopy	82.4	75.5
	19.6	20.9
% Dead canopy	13.8	21.1
	15.6	19.9
Oster Lake		
% Live vegetation	14.8	17.7
	14.0	13.5
% Litter	41.3	34.1
	36.0	30.0
% Bare ground	40.5	46.8
	34.6	31.7
% Moss	3.4	1.4
	9.8	2.6
% Live canopy	82.1	80.4
	18.5	16.5
% Dead canopy	12.6	10.3
	12.2	11.1
Ellerslie		
% Live vegetation	17.6	12.0
	14.9	11.5
% Litter	36.9	15.4
	28.3	14.8
% Bare ground	42.8	72.3
	31.0	19.1
% Moss	2.6 a	0.3 b
	5.6	1.0
% Live canopy	53.9	50.6
	20.7	20.9
% Dead canopy	27.3	14.7
	19.0	10.8

[1] Mean, [2] Standard Deviation

Values in a row sharing same letter are not significantly different at $\alpha=0.05$

Fill colour indicates values affected by one or more two or three-way interactions

Table 3.11. Mean density, biovolume and density-biovolume of species in season treatments in July 1999 at Ellerslie and Tawayik Lake and Oster Lake, Elk Island National Park

Species	Density (plants m^{-2})		% Biovolume		Density-Biovolume	
Summation	Fall	Spring	Fall	Spring	Fall	Spring
Tawayik Lake						
All species	542 [1]	545				
	174 [2]	200				
Seeded species	24	51	41	75	74	185
	14	51	26	22	64	197
Seeded grasses	19	42	40	73	71	182
	12	49	26	23	64	198
Seeded forbs	5	9	1 b	2 a	2	3
	8	12	4	4	12	9
Non-seeded species	518	494	59	25	469	134
	171	189	26	22	386	138
Non-seeded grasses	15 b	54 a	3	5	6 b	22 a
	19	61	6	6	13	35
Non-seeded forbs	503	440	56	20	463	112
	173	167	26	20	386	125
Oster Lake						
All species	155	198				
	99	107				
Seeded species	26	36	46	58	86	108
	23	22	28	29	89	74
Seeded grasses	16	26	40	50	63	90
	10	16	28	30	58	68
Seeded forbs	10	10	6	8	22	18
	19	15	15	17	75	44
Non-seeded species	129	162	54	42	222 a	176 b
	100	108	28	29	412	208
Non-seeded grasses	7	10	2	3	4	9
	21	13	8	6	10	28
Non-seeded forbs	122	152	52	39	218	167
	95	108	27	28	412	207
Ellerslie						
All species	381	396				
	211	178				
Seeded species	30	28	81	86	124	138
	21	14	19	17	65	95
Seeded grasses	21 b	22 a	74	78	110	131
	9	12	23	24	60	100
Seeded forbs	9	6	8	7	14	8
	18	10	16	17	38	19
Non-seeded species	351	369	19	14	71	59
	212	178	19	17	66	46
Non-seeded grasses	15	4	1	1	3	2
	49	16	3	7	7	12
Non-seeded forbs	336	364	18	13	68	57
	199	176	19	16	65	46

[1] Mean, [2] Standard Deviation

Values in a row sharing same letter are not significantly different at $\alpha=0.05$

Fill colour indicates values affected by one or more two and three-way interactions

Table 3.12. Mean density (plants m^{-2}) of seeded species in three treatments in July 1999

	Season		Mowing		Mix					
Species	Fall	Spring	Mow	Unmow	1	2	3	4	Mean	SD
Tawayik Lake										
Agropyron dasystachyum	0	6	4	3	3	5	2	3	3.1	1.7
Agrostis stolonifera	0	2	1	1	0	2	1	2	1.0	0.6
Agropyron trachycaulum	15	21	19	17	16	19	19	19	18.1	1.9
Bouteloua gracilis	0	0	0	0	0	0	0	0	0.0	0.0
Bromus carinatus	0	2	3	0	0	5	0	0	1.3	1.8
Festuca hallii	0	2	1	1	0	3	0	2	1.2	1.0
Festuca ovina	0	4	4	0	0	8	0	0	2.1	3.1
Koeleria macrantha	0	0	0	0	0	0	0	0	0.0	0.0
Poa palustris	3	1	2	2	2	3	0	2	1.8	0.8
Stipa viridula	0	4	2	2	3	3	1	2	2.1	1.3
Achillea millefolium	3	3	3	3	1	2	7	2	2.9	1.8
Aster laevis	0	0	0	0	0	0	0	0	0.0	0.0
Gaillardia aristata	0	0	0	0	0	0	0	0	0.0	0.0
Linum lewisii	0	0	0	0	0	0	1	0	0.2	0.2
Monarda fistulosa	0	0	0	0	0	0	0	0	0.1	0.1
Petalostemon purpureum	0	0	0	0	0	0	0	0	0.0	0.0
Ratibida columnifera	0	1	0	0	0	0	1	0	0.3	0.4
Solidago canadensis	0	0	0	0	0	0	1	0	0.1	0.2
Solidago missouriensis	0	0	0	0	0	0	1	0	0.1	0.2
Vicia americana	2	4	3	3	2	3	3	4	3.1	0.9
Unidentified forb	0	0	0	0	0	0	0	0	0.0	0.0
Oster Lake										
Agropyron dasystachyum	1	7	3	5	2	7	4	3	3.9	2.0
Agrostis stolonifera	1	1	1	0	1	1	1	1	0.8	0.4
Agropyron trachycaulum	14	14	12	15	15	12	15	14	13.6	1.2
Bouteloua gracilis	0	0	0	0	0	0	0	0	0.0	0.0
Bromus carinatus	0	0	0	0	0	0	0	0	0.1	0.1
Festuca hallii	0	0	0	0	0	1	0	0	0.2	0.2
Festuca ovina	0	0	0	0	0	0	0	0	0.0	0.0
Koeleria macrantha	0	0	0	0	0	0	0	0	0.0	0.0
Poa palustris	0	3	1	2	0	1	1	4	1.4	1.3
Stipa viridula	1	2	1	1	2	1	1	1	1.1	0.4
Achillea millefolium	9	5	7	7	6	5	6	12	7.1	2.3
Aster laevis	0	0	0	0	0	0	0	0	0.0	0.0
Gaillardia aristata	0	0	0	0	0	0	1	1	0.3	0.3
Linum lewisii	0	1	1	0	0	0	1	1	0.4	0.4
Monarda fistulosa	0	0	0	0	0	0	0	0	0.1	0.1
Petalostemon purpureum	0	0	0	0	0	0	0	0	0.1	0.1
Ratibida columnifera	0	1	0	1	0	0	1	2	0.6	0.6
Solidago canadensis	0	0	0	0	0	0	0	0	0.1	0.1
Solidago missouriensis	0	0	0	0	0	0	0	1	0.2	0.2
Vicia americana	0	2	2	1	1	0	2	2	1.2	0.7
Unidentified forb	0	0	0	0	0	0	0	0	0.0	0.0

Table 3.12. Mean density (plants m^{-2}) of seeded species in three treatments in July 1999 (cont'd)

	Season		Mowing		Mix					
Species	Fall	Spring	Mow	Unmow	1	2	3	4	Mean	SD
Ellerslie										
Agropyron dasystachyum	3	3	2	4	4	2	2	2	2.7	0.9
Agrostis stolonifera	0	1	1	1	0	1	0	2	0.8	0.7
Agropyron trachycaulum	14	15	14	15	17	13	15	13	14.6	1.2
Bouteloua gracilis	0	0	0	0	0	0	0	0	0.0	0.0
Bromus carinatus	0	0	0	0	0	0	0	0	0.0	0.0
Festuca hallii	0	1	0	1	0	1	0	1	0.5	0.4
Festuca ovina	0	0	0	0	0	0	0	0	0.0	0.0
Koeleria macrantha	0	0	0	0	0	0	0	0	0.2	0.1
Poa palustris	1	0	1	1	0	1	0	2	0.8	0.6
Stipa viridula	2	1	2	1	2	2	1	1	1.5	0.4
Achillea millefolium	2	1	3	1	0	0	4	3	1.6	1.3
Aster laevis	0	0	1	0	0	0	1	1	0.4	0.4
Gaillardia aristata	1	1	1	1	0	0	2	2	0.9	0.7
Linum lewisii	1	0	1	0	0	0	1	1	0.5	0.5
Monarda fistulosa	1	0	1	1	0	0	2	1	0.7	0.8
Petalostemon purpureum	0	0	0	0	0	0	0	0	0.0	0.0
Ratibida columnifera	0	1	0	0	0	0	1	0	0.3	0.4
Solidago canadensis	0	0	0	0	0	0	0	0	0.0	0.0
Solidago missouriensis	0	0	0	0	0	0	0	1	0.2	0.2
Vicia americana	3	2	3	3	0	0	6	5	2.7	1.9
Unidentified forb	0	0	0	0	0	0	0	0	0.0	0.0

Table 3.13. **Species richness (number of species per m^2) in twelve treatments in July 1999 Ellerslie and Tawayik Lake and Oster Lake, Elk Island National Park**

	Fall Mow				Fall Unmow				Spring Mow				Spring Unmow						
Site/Species	Mix 1	Mix 2	Mix 3	Mix	Mix 1	Mix 2	Mix 3	Mix 4	Mix 1	Mix 2	Mix 3	Mix	Mix 1	Mix 2	Mix 3	Mix	Mean	SD	Summation[1]
Tawayik Lake																			6.0
Grasses present	2	5	4	4	3	2	1	3	3	7	2	5	4	7	4	5	3.8	1.7	
Grasses seeded	6	10	6	10	6	10	6	10	6	10	6	10	6	10	6	10	8.0		
Forbs present	2	2	2	1	1	1	2	2	2	2	6	2	2	1	3	4	2.2	1.3	
Forbs seeded	0	0	10	10	0	0	10	10	0	0	10	10	0	0	10	10	5.0		
Oster Lake																			6.1
Grasses present	3	6	2	3	1	2	1	1	4	6	3	5	3	6	4	6	3.5	1.9	
Grasses seeded	6	10	6	10	6	10	6	10	6	10	6	10	6	10	6	10	8.0		
Forbs present	2	1	2	1	1	2	3	3	2	2	5	4	2	0	6	6	2.6	1.8	
Forbs seeded	0	0	10	10	0	0	10	10	0	0	10	10	0	0	10	10	5.0		
Ellerslie																			7.8
Grasses present	4	6	4	4	4	5	5	5	3	6	4	7	3	6	3	5	4.6	1.2	
Grasses seeded	6	10	6	10	6	10	6	10	6	10	6	10	6	10	6	10	8.0		
Forbs present	0	2	6	7	0	0	6	6	0	0	8	6	0	0	5	5	3.2	3.1	
Forbs seeded	0	0	10	10	0	0	10	10	0	0	10	10	0	0	10	10	5.0		

[1] Value is the summation of means for grasses present and forbs present

Table 3.14. Wilcoxon z-score for species richness (number of species per m^2) of grasses and forbs seeded versus present in July 1999 at Ellerslie and Tawayik Lake and Oster Lake, Elk Island National Park

Site	Season	Mow	Mix	Grasses seeded versus present	Forbs seeded versus present
Ellerslie				0.0001*	0.2965
Oster				0.0001*	0.8926
Tawayik				0.0001*	1.0000
Ellerlsie	Fall			0.0014*	0.5420
	Spring			0.0014*	0.3946
Oster	Fall			0.0015*	1.0000
	Spring			0.0048*	0.8715
Tawayik	Fall			0.0008*	1.0000
	Spring			0.0120*	1.0000
Ellerlsie		Mow		0.0100*	0.5429
		Unmow		0.0014*	0.3954
Oster		Mow		0.0027*	1.0000
		Unmow		0.0027*	0.8717
Tawayik		Mow		0.0033*	1.0000
		Unmow		0.0033*	1.0000
Ellerslie			1	0.0194*	1.0000
			2	0.0177*	0.4533
			3	0.0202*	0.0202*
			4	0.0202*	0.0211*
Oster			1	0.0202*	0.0177*
			2	0.0177*	0.0668
			3	0.0211*	0.0211*
			4	0.0211*	0.0211*
Tawayik			1	0.0202*	0.0177*
			2	0.0202*	0.0194*
			3	0.0202*	0.0202*
			4	0.0202*	0.0202*

*** indicates value significant at α=0.05**

Table 3.15. Mean percent ground and canopy cover in season treatments in July 1999 at Ellerslie Ellerslie and Tawayik Lake and Oster Lake, Elk Island National Park

Parameter	Fall	Spring
Tawayik Lake		
% Live vegetation	14.4[1]	17.6
	12.4[2]	17.8
% Litter	53.5	58.5
	31.9	31.1
% Bare ground	32.2	22.9
	30.0	25.4
% Moss	0.0	1.0
	0.0	4.6
% Live canopy	78.1	74.8
	16.6	22.3
% Dead canopy	18.2	20.9
	15.5	18.8
Oster Lake		
% Live vegetation	9.2	12.2
	5.4	6.9
% Litter	57.8	46.2
	28.4	27.3
% Bare ground	30.4	40.0
	26.2	24.9
% Moss	2.6	1.7
	7.0	3.6
% Live canopy	92.5	87.9
	9.1	10.1
% Dead canopy	6.4	9.5
	7.2	7.8
Ellerslie		
% Live vegetation	13.5	12.2
	7.5	7.0
% Litter	17.1 a	4.9 b
	22.8	6.6
% Bare ground	59.9 b	79.5 a
	23.5	14.0
% Moss	9.6 a	3.5 b
	10.3	9.1
% Live canopy	52.8	39.0
	27.3	24.1
% Dead canopy	22.9	19.1
	18.7	13.1

[1] Mean, [2] Standard Deviation

Values in a row sharing same letter are not significantly different at $\alpha=0.05$

Fill colour indicates values affected by one or more two or three-way interactions

Table 3.16. Mean density, biovolume and density-biovolume of species in mow treatments in May 1999 at Ellerslie and Tawayik Lake and Oster Lake, Elk Island National Park

Species Summation	Density (plants m^{-2}) Mow	Density (plants m^{-2}) Unmow	% Biovolume Mow	% Biovolume Unmow	Density-Biovolume Mow	Density-Biovolume Unmow
Tawayik Lake						
All species	566 [1]	614				
	282 [2]	315				
Seeded species	38	24	31	29	121	62
	54	20	28	28	287	81
Seeded grasses	33	18	30	28	118	60
	52	16	28	28	286	81
Seeded forbs	6	6	1	1	3	2
	15	10	5	3	17	12
Non-seeded species	528	590	69	71	815	755
	272	306	28	28	645	572
Non-seeded grasses	40	41	3	3	13	8
	84	66	6	5	39	12
Non-seeded forbs	488	549	66	69	802	747
	244	281	28	28	647	573
Oster Lake						
All species	345	377				
	269	241				
Seeded species	30	31	43	49	81	101
	20	24	25	29	75	88
Seeded grasses	22	21	35	40	60	82
	15	18	25	30	59	85
Seeded forbs	8	10	8	9	21	19
	15	16	16	17	56	46
Non-seeded species	316	346	57	51	421	345
	267	239	25	29	590	613
Non-seeded grasses	9	8	3	2	6	6
	18	14	7	5	19	22
Non-seeded forbs	307	338	54	49	415	339
	264	236	25	28	591	614
Ellerslie						
All species	460 b	548 a				
	212	252				
Seeded species	34	38	70	73	136	177
	23	35	28	29	96	262
Seeded grasses	25	30	64	69	126	170
	18	32	29	30	99	263
Seeded forbs	9	8	6	3	10	7
	17	16	14	9	28	19
Non-seeded species	426 b	509 a	30	27	182	172
	213	251	28	29	388	228
Non-seeded grasses	48 b	118 a	3	5	15 b	30 a
	84	145	10	14	45	64
Non-seeded forbs	379	392	27	22	166	142
	192	207	27	26	388	217

[1] Mean, [2] Standard Deviation

Values in a row sharing same letter are not significantly different at $\alpha=0.05$

Fill colour indicates values affected by one or more two or three-way interactions

Table 3.17. Mean percent ground and canopy cover in mow treatments in May 1999 at Ellerslie and Tawayik Lake and Oster Lake, Elk Island National Park

Parameter	Mow	Unmow
Tawayik Lake		
% Live vegetation	33.4 [1]	40.9
	24.4 [2]	25.5
% Litter	36.0 a	22.8 b
	29.2	20.6
% Bare ground	29.9	36.0
	24.7	25.5
% Moss	0.8	0.4
	3.5	1.2
% Live canopy	85.7 a	72.2 b
	14.9	23.0
% Dead canopy	11.1 b	23.8 a
	13.0	20.4
Oster Lake		
% Live vegetation	17.4	15.1
	14.2	13.3
% Litter	41.8	33.6
	34.9	31.4
% Bare ground	39.7	47.6
	34.4	31.8
% Moss	1.1	3.7
	2.6	9.8
% Live canopy	85.3 a	77.2 b
	15.1	18.9
% Dead canopy	8.4 b	14.6 a
	9.8	12.6
Ellerslie		
% Live vegetation	15.0	14.6
	14.1	13.1
% Litter	27.1	25.2
	26.2	23.9
% Bare ground	56.5	58.6
	30.3	29.0
% Moss	1.3	1.6
	3.0	5.1
% Live canopy	55.3 a	49.2 b
	20.9	20.3
% Dead canopy	19.6 b	22.5 a
	16.1	17.1

[1] Mean, [2] Standard Deviation

Values in a row sharing same letter are not significantly different at α=0.05

Fill colour indicates values affected by one or more two or three-way interactions

Table 3.18. Mean density, biovolume and density-biovolume of species in mow treatments in July 1999 at Ellerslie and Tawayik Lake and Oster Lake, Elk Island National Park

Species	Density (plants m^{-2})		% Biovolume		Density-Biovolume	
Summation	Mow	Unmow	Mow	Unmow	Mow	Unmow
Tawayik Lake						
All species	533[1]	554				
	195[2]	179				
Seeded species	42	33	58	58	146	113
	51	21	30	28	205	83
Seeded grasses	35	26	56	57	144	109
	50	18	31	29	205	83
Seeded forbs	7	7	1	1	2	3
	10	11	4	5	7	13
Non-seeded species	491	521	42	42	320	283
	179	181	30	28	399	256
Non-seeded grasses	36	33	4	4	12	16
	51	47	6	7	19	34
Non-seeded forbs	455	488	38	38	308	268
	165	179	29	29	400	258
Oster Lake						
All species	179	174				
	114	97				
Seeded species	29	34	50	54	92	102
	25	21	30	28	92	73
Seeded grasses	19	23	42	47	66	87
	12	15	31	27	60	67
Seeded forbs	10	10	8	6	26	15
	19	14	19	12	78	37
Non-seeded species	150	141	50	46	180	218
	114	96	30	28	187	422
Non-seeded grasses	10	6	3	3	8	5
	22	10	6	8	28	11
Non-seeded forbs	140	134	48	43	172	213
	110	95	30	26	185	422
Ellerslie						
All species	393	384				
	184	206				
Seeded species	28	29	85	83	130	132
	19	17	17	19	72	90
Seeded grasses	20	22	77	75	119	121
	9	12	22	24	70	94
Seeded forbs	8	7	8	7	12	10
	16	14	16	18	33	27
Non-seeded species	365	355	15	17	61	68
	184	207	17	19	51	63
Non-seeded grasses	4	15	1	1	2	3
	11	51	4	6	6	12
Non-seeded forbs	361	340	15	16	60	65
	184	193	17	19	51	62

[1] Mean, [2] Standard Deviation

Values in a row sharing same letter are not significantly different at α=0.05

Fill colour indicates values affected by one or more two or three-way interactions

Table 3.19. Mean percent ground and canopy cover in mow treatments in July 1999 at Ellerslie and Tawayik Lake and Oster Lake, Elk Island National Park

Parameter	Mow	Unmow
Tawayik Lake		
% Live vegetation	18.3 [1] a	13.7 b
	17.7 [2]	12.2
% Litter	56.9	55
	31.3	31.8
% Bare ground	23.9 b	31.2 a
	26.5	29.4
% Moss	0.9	0.1
	4.6	0.6
% Live canopy	75.9	77.0
	20.5	18.9
% Dead canopy	20.6 a	18.5 b
	18.5	15.9
Oster Lake		
% Live vegetation	11.2	10.2
	6.5	6.3
% Litter	50.5	53.5
	28.2	28.6
% Bare ground	36.0	34.4
	26.4	25.6
% Moss	2.4	1.9
	5.0	6.2
% Live canopy	92.3	88.0
	7.9	11.2
% Dead canopy	6.7	9.2
	7.1	8.0
Ellerslie		
% Live vegetation	14.0 a	11.7 b
	7.9	6.4
% Litter	12.1	9.8
	19.3	16.2
% Bare ground	66.9	72.5
	23.0	19.8
% Moss	7.0	6.1
	11.0	9.3
% Live canopy	52.6 a	39.2 b
	28.0	23.5
% Dead canopy	19.2	22.8
	14.3	17.8

[1] Mean, [2] Standard Deviation

Values in a row sharing same letter are not significantly different at $\alpha=0.05$

Fill colour indicates values affected by one or more two or three-way interactions

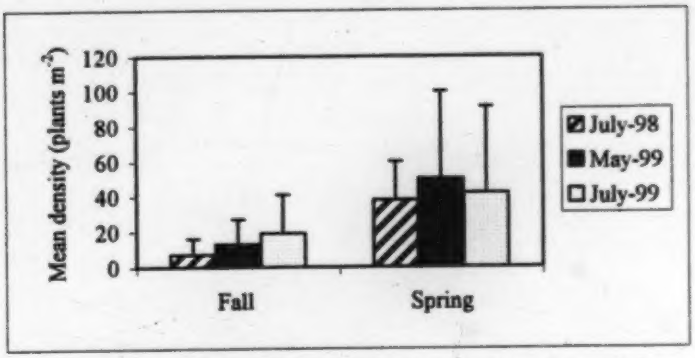

Figure 3.1. Mean density of seeded grasses in fall and spring seeded treatments at Tawayik Lake

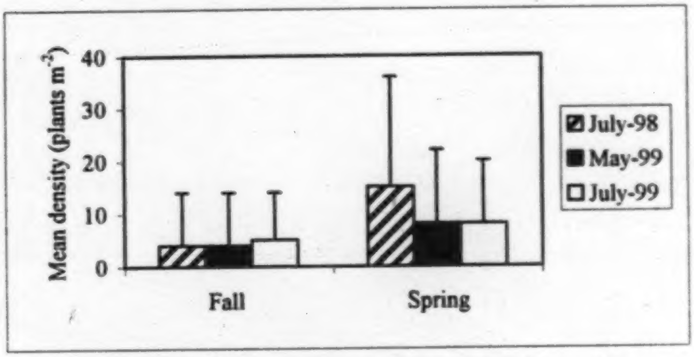

Figure 3.2. Mean density of seeded forbs in fall and spring seeded treatments at Tawayik Lake

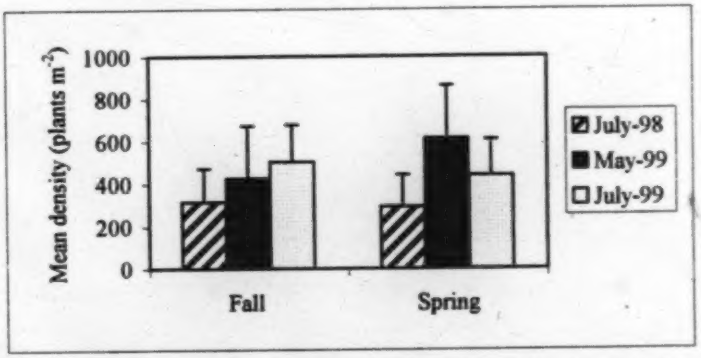

Figure 3.3. Mean density of non-seeded forbs in fall and spring seeded treatments at Tawayik Lake

[1] Error bars indicate standard deviation

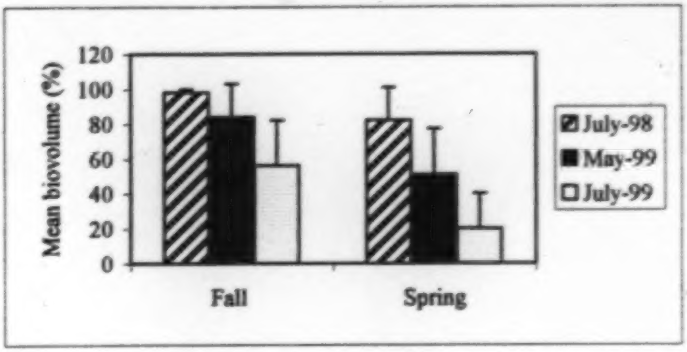

Figure 3.4. Mean biovolume of non-seeded forbs in fall and spring seeded treatments at Tawayik Lake

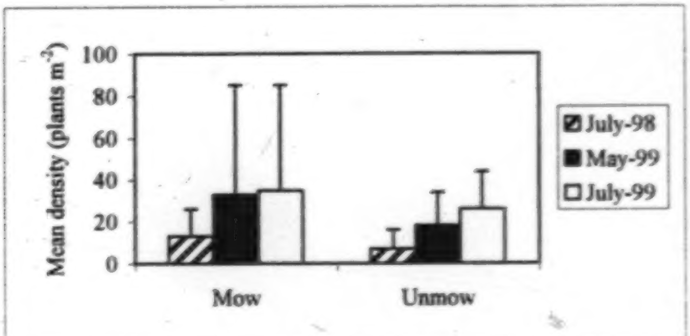

Figure 3.5. Mean density of seeded grasses in mow and unmow treatments at Tawayik Lake

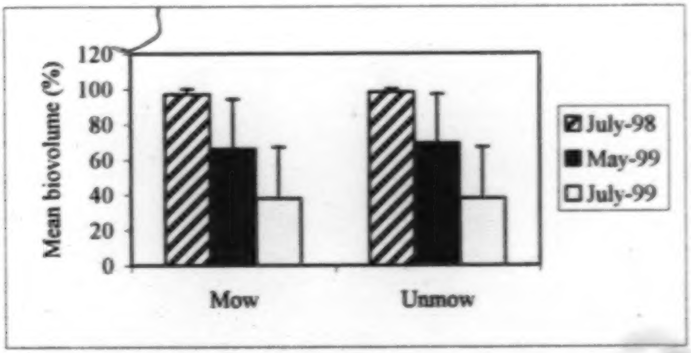

Figure 3.6. Mean biovolume of non-seeded forbs in mow and unmow treatments at Tawayik Lake

[1] Error bars indicate standard deviation

CHAPTER IV. ROLE OF SEED MIX RICHNESS IN PLANT COMMUNITY DEVELOPMENT

1.0. INTRODUCTION

The recent work of Chapin et al. (1998), Frank and McNaughton (1991), Grime (1997, 1998), Huston (1997), Kareiva (1994, 1996), May (1972), McNaughton (1977), Naeem and Li (1997), Pimm (1979, 1984), Pimm et al. (1995), Tilman (1994, 1996a, 1996b, 1999), Tilman and Downing (1994) and Tilman et al. (1994, 1996, 1997) has brought the issue (and controversy) of biodiversity to the forefront of current ecological literature. Plant community biodiversity is a function of species richness and the relative abundance of species (Begon et al. 1990). At the heart of the biodiversity debate is the issue of whether or not biodiversity contributes to ecosystem stability. Understandably, there is a desire to see the claim realized as a potential means of protecting and restoring damaged ecosystems.

Elton (1958) first suggested the diversity-stability hypothesis. He believed ecosystem functioning was sensitive to biodiversity, citing as evidence the greater frequency of pest outbreaks in croplands versus complex grasslands. Stability is the tendency for population perturbations to dampen, thus returning the system to a consistent state (May 1974). Hutchinson (1959) claimed the greater number of links in a system, the greater the chance of damping oscillations. However, May (1974) presented mathematical evidence that, on an individual species basis, diverse ecosystems are less stable than simple systems. The mathematical model showed diverse ecosystems had more complex webs of interaction among species and, therefore, larger repercussions of disturbance among species. Thus, the model rejected Elton's diversity-stability hypothesis by illustrating the greater the size and connectedness of the system, the larger number of oscillation modes it possesses, thereby increasing the chance of instability. Despite this conclusion, the current literature still debates biodiversity's role in ecosystem stability.

From the biodiversity issue arose questions of the factors affecting ecosystem processes. Leps (1982) and Grime (1997) suggested functional or biological characteristics of dominant plants control ecosystem processes. This is referred to as the species-redundancy hypothesis (Walker 1992), which asserts that many species are similar and ecosystem functioning is independent of diversity, assuming major functional groups are present. If ecosystem stability and function rely on species processes, rather than species richness or biodiversity, the establishment of a stable community hinges on inclusion of key functional species, rather than a wide diversity of species.

McNaughton (1977) found species diversity and functional diversity are both important. Species may have similar ecosystem function, but differ in their response to environmental change. Having a diversity of species will provide stability, because a decrease in the abundance of one species will be compensated for by an increase in another functionally similar species. The more functionally similar species in the plant community, the greater the community resilience in responding to the environmental change. Tilman et al. (1997) found both function diversity and species diversity impacted ecosystem processes, but determined that functional diversity had a greater influence.

Biotic and abiotic factors, including heterogeneity, nutrient availability, area size and disturbance regime (Grubb 1986), determine the diversity of species that can be supported in a given area (Connell and Orias 1964). Swift (in Basin 1994) found little productivity was gained by adding more than four or five agronomic species. Tilman and Downing (1994) found the effects of biodiversity in grasslands plateaued at 10 species.

A comparison of popular models reveals tradeoffs among their strengths, with no single model achieving universal acceptance and applicability. From an application perspective in reclamation, three important questions remain unanswered. How does species richness of the seed mix affect plant community composition during the first two growing seasons? How does species richness of the seed mix influence the measured parameters of seeded and non-seeded species? Does species richness affect ground cover and canopy cover in the plant community?

2.0. OBJECTIVES AND HYPOTHESES

2.1. Research Objectives

- To compare the species richness and composition of the plant community to that of the seed mix.
- To determine if the density, percent biovolume and density-biovolume of the six grasses common to the four mixes changed with seed mix richness.
- To determine whether seed mix richness affected ground and canopy cover.
- To determine whether seed mix richness affected non-seeded species density, percent biovolume and density-biovolume.

2.2. Hypotheses

- Community richness will be determined by competition, which itself is a factor of environmental and site conditions during development. Although species richness of the seed mix cannot be denied influence, its effect may only be measured in terms of biological significance.
- As the richness of the seed mix increases, there will be significant increases in the density, percent biovolume and density-biovolume of the plant community.
- Increasing seed mix richness theoretically increases the number of species competing for light, nutrients, water and space. Because competition is considered to be a factor in maintaining low species diversity, it is hypothesized that increasing seed mix richness should decrease the density, percent biovolume and density-biovolume of non-seeded species.
- Increasing seed mix richness theoretically increases the diversity of physiological traits in the vegetation community, allowing for greater utilization of light, nutrients, water and space. It is hypothesized that increasing seed mix richness will increase ground and canopy cover.

3.0. RESEARCH SITE DESCRIPTION AND EXPERIMENTAL DESIGN

3.1. Site Description

One research site is located at the University of Alberta Ellerslie Research Station, in southern Edmonton. Two Elk Island National Park sites are located approximately 50 km east of Edmonton and separated from each other by a distance of approximately 3 km. All sites are in the Aspen Parkland ecoregion. For a more detailed description see Chapter 2.

The Aspen Parkland ecoregion has a subhumid to humid continental climate (Strong and Leggat 1992). Mean annual precipitation is 450 mm, 78% of which occurs as summer precipitation (Strong and Leggat 1992). The ecoregion is characterized by undulating to hummocky glacial till deposits (Crown 1977). Both sites are underlain by pre-Cambrian bedrock of the Edmonton formation, a brackish water formation composed of sandy shales and bentonitic sandstone, clay and coal seams. The soil at the Ellerslie site is a Gleyed and Gleyed Eluviated Black Chernozem and is mapped as the Malmo soil series (Bowser et al. 1962). Oster Lake soil is a Dark Gray Luvisol and Tawayik Lake soil is a Dark Gray and Gleyed Dark Gray Luvisol (Hammermeister 1998). Moss (1955) described parkland as a mosaic of prairie patches and aspen groves, with prairie occupying the drier situations and aspen the more moist and sheltered places.

3.2. Experimental Design

There are four blocks at Ellerslie and two each at Oster and Tawayik Lakes (Figures 2.1 and 2.2). Each block is divided lengthwise into fall and spring seeded treatments. In 1998, the fall seeded treatment was split in half lengthwise (split plot design) into mowed and unmowed treatments. In 1999, both fall and spring seeded treatments were split in half lengthwise (split-split plot design) into mowed and unmowed treatments. Within each season and mowing treatment of each block are four seed mixes. Each plot is 12.6 m long and 8.84 m wide, and is bordered on all sides by a 1 m interplot area.

Four seed mixes of species common to the Aspen Parkland were used for this research (Table 2.1, Appendix A). The mixes were designed with equal amounts of pure live seed (PLS) of each species per vegetation type (grass or forb); grass-forb mixes were composed of 70% grasses and 30% forbs (Appendix B).

4.0. MATERIALS AND METHODS

4.1. Vegetation

Fall and spring seeded species were assessed in late July 1998, late May 1999 and late July 1999. Ten 0.1 m^2 quadrats were randomly located in each plot (five in mow, five in unmow). Quadrat number was determined by calculating the point at which the species curve reached a stable point, or the point where the number of species in each quadrat became constant (Braun-Blanquet 1932, Raunkiaer 1934).

The vegetation parameters assessed were: species plant density, percent biovolume, percent ground cover (live vegetation, litter, bare ground and moss) and percent live/dead canopy. Density was defined as the number of whole living plants and dead plants from the current growing season in a given area. Percent biovolume was the visual estimation of the volume of a species, as a percent of the total volume of vegetation in the quadrat. Percent ground cover was measured at 1 cm above ground level. For this measurement, litter was defined as the previous year's growth. Percent live/dead canopy was determined by a visual estimation of the canopy when viewed from above.

4.2. Statistical Analyses

Density, percent biovolume, percent canopy and ground cover data were sorted by site (Tawayik Lake, Oster Lake and Ellerslie) and analyzed according to species grouping (seeded species, seeded grasses, seeded forbs, non-seeded species, non-seeded grasses, non-seeded forbs and total species). Density-biovolume was calculated by multiplying density by percent biovolume (per species per quadrat).

SAS for Windows V6.12 was the statistical software used. The mathematical models, including sample size and degrees of freedom, are described in Appendix C. The General Linear Model (GLM) was used to test for interaction and significance of main effects (season-mow and mix in 1998; season, mow and mix in 1999). Orthogonal contrasts were used where an interaction or effect was significant. Theoretically, a significant interaction of the main effects would preclude their independent examination. However, orthogonal contrasts were conducted on main effects influenced by a significant interaction and results were discussed accordingly. A p-value of less than 0.05 is sufficient to reject the null hypothesis in each of the following analyses (Mapfumo 1999).

Species richness was analyzed using total number of species m^{-2}. A Wilcoxon signed rank test was used to determine if a statistically significant difference occurred between what was seeded and what was present. The number of grass and the number of forb species seeded versus present was compared at each site, and within each site between the mix treatments.

Post-hoc comparisons between years were conducted using the t-test for paired observations, where sample size was the same. No comparison could be conducted between years where sample size differed.

5.0. RESULTS

5.1. Interactions

In ecological field research, treatment effects are often difficult to separate (Givnish 1994, Huston 1997). Because natural processes tend not to act in isolation, interaction among treatments is expected. When interaction does occur, more than one treatment has likely influenced the result and, therefore, the result cannot be grouped with data unaffected by interaction. In this research interactions were extremely varied and lacked a common pattern, making them very difficult to summarize. Data affected by treatment effect interactions are clearly identified in Tables 3.1 to 3.19. In Appendix D tables contain values of significance for interaction between main effects and orthogonal contrasts for significant interactions. These tables should be consulted for interaction detail which cannot be easily summarized.

5.2. Richness and Composition of the Seed Mix versus the Plant Community

Significantly fewer grass species were present in the plant community than were seeded. One third to one half of grass species seeded were present and approximately half the forb species seeded were present by the end of the first growing season (Tables 3.3 and 3.4). Five to six species were usually present in a given community (Table 3.3, Figures 4.1 and 4.2). The most common species were *Agropyron dasystachyum*, *A. trachycaulum*, *Stipa viridula, Achillea millefolium* and *Vicia americana*. The success of the latter two species may be affected by their presence in the seedbank and surrounding area, which overestimated their density values. Among the sites, 18 of 20 seeded species were present; *Bromus carinatus* and *Festuca ovina* were not observed (Table 3.2). Within each mix community, the density of each grass (or forb) species should equal all other grass (or forb) species, as each was seeded at the same PLS rate (Appendix B). However, species densities were not equal in the mix communities (Table 3.2.

The highest species richness was associated with the communities of mix two for grasses and mix three for forbs in spring unmow and fall mow treatments (Table 3.3). Mix did not have an effect on species richness in the fall unmow treatment.

By the beginning of the second growing season, one to two thirds of grass species seeded and one to two thirds of forb species seeded were present (Table 3.8). Overall, five to eight species were present (Table 3.8). The most common species were the same as those from the first growing season with the addition of *Poa palustris* (Table 3.7).

Species densities were still clearly not equal within each mix community; the two wheatgrasses dominated the grasses, while *Bromus carinatus* remained absent. Forb densities were also unequal and frequently dominated by *A. millefolium* and *V. americana*. Again, 18 of 20 seeded species were present (Table 3.7). Trends for species richness were similar to those in the first growing season. The highest species richness was associated with the communities of mix 2 for grasses and mix 3 for forbs, regardless of season or mowing treatment (Table 3.8).

By the end of the second growing season, 40 to 60% of the grass and forb species seeded were present in the plant community (Table 3.13). On average, six to eight species were present (Table 3.13). The species most common in the first and early second growing seasons were still so at this time, in addition to *Gaillardia aristata* and *Ratibida columnifera* at most sites (Table 3.12).

Species densities remained unequal within each mix community (Table 3.12). The two wheatgrasses, especially *A. trachycaulum*, dominated the grasses. *Bouteloua gracilis* was absent. Although present in the two previous vegetation assessments it may have passed the peak of its growing season prior to the final assessment. Despite its absence during the first and early second growing seasons, *Bromus carinatus* was present in the late second growing season. Forb densities remained unequal and were dominated by *A. millefolium* and *V. americana.* All seeded forb species were present, but their average densities were low in comparison to the two dominant forb species.

The highest species richness was still associated with the communities of mix 2 for grasses and mix 3 for forbs, regardless of season or mowing treatment (Table 3.13). The moderate species richness from mixes 2 and 3 may have provided the most beneficial level of competition among species to create the most species rich community. Mixes with more species were not associated with communities of greater species richness. Typically one to two thirds of the seeded species were present in the plant community.

5.3. Effect of Seed Mix Richness on Common Grasses

Species richness of the mixes ranged from 6 to 20. Each of the six common grasses was 17% of the PLS in mix 1, 10% in mix 2, 12% in mix 3 and 7% in mix 4 (Appendix B).

The density, percent biovolume and density-biovolume were occasionally, but not consistently, affected by PLS composition (Table 4.1, Figures 4.3 and 4.4). Common grass parameters did not increase with species richness of the seed mix.

Parameters varied only slightly among the four mixes with few significant differences among mixes (it was usually mix two that was different from the other mixes).

By early in the second growing season, there were several significant differences among the mixes (Table 4.2). Parameters for *Agropyron trachycaulum* in mixes 1 and 2 were often significantly different from other mixes. Parameters for *Festuca hallii* in mix 2 were often significantly different than other mixes and were sometimes not significantly different from mix 4. The remaining species were not affected by mix.

By the end of the second growing season, the parameters remained unaffected by the PLS composition and species richness (Table 4.3). Most differences among mixes occurred for *A. trachycaulum* and *F. hallii*. Although there was no consistent pattern for *A. trachycaulum*, the trend present earlier in the growing season continued for *F. hallii* (either mix 2 differed from all other mixes, or it was not different from mix 4). The remaining species were not affected by mix.

Greater species richness of the seed mix did not increase seeded species density, percent biovolume or density-biovolume in the community. The amount of PLS in each mix had no effect on the density, density-biovolume or density-biovolume of seeded species.

5.4. Seed Mix Richness and the Presence of Non-Seeded Species

No single mix was consistently associated with the highest or lowest density, percent biovolume or density-biovolume of non-seeded grasses or non-seeded forbs (Table 4.4 and Figure 4.5). Although there were significant differences for some data, no conclusions can be drawn based on these differences. Mix 2 has the highest value of all mixes in almost half of the data values.

Non-seeded species dominated the first year plant community; comprising most of the community density and biovolume and therefore had the greatest influence on the dynamics of community development. It is, therefore, ecologically unreasonable to expect a significant effect of seed mix richness on the presence of non-seeded species. By early in the second growing season, non-seeded species parameters were generally not affected by seed mix richness. The only trend was mix 1 had the lowest percent biovolume of non-seeded species (Table 4.5).

By the end of the second growing season, seed mix richness generally did not affect non-seeded species. The density of non-seeded grasses was significantly higher than other mixes at two sites (Table 4.6). Greater seed mix richness was not associated with an increase or decrease in the density, percent biovolume or density-biovolume of non-seeded species. Although still present, most non-seeded species were much less visible and most were perennial species, not the annual species present in such large numbers the year previous. The difference between mixes was visually observable and was not marred by the presence of non-seeded species.

5.5. Ground and Canopy Cover in Four Mixes

Increasing species richness of seed mixes was not associated with greater ground or canopy cover. Mix 3 was consistently associated the highest percent live vegetation; mix 3 was significantly different from the other mixes at two sites (Table 4.7). Plant communities for all four mixes had high bare ground; mix 3 consistently produced the least amount. No mix was consistently associated with the highest live or dead canopy cover.

Early in the second growing season, increasing species richness of seed mixes was not associated with increasing ground or canopy cover. Mix 1 replaced mix 3 as the mix associated with the highest percent live vegetation (Table 4.8). By the end of the second growing season, increasing species richness of seed mixes was not associated with increasing ground cover or canopy. Live vegetation cover was no longer affected by mix (Table 4.9). Mix 1 was associated with the highest moss and dead canopy cover.

6.0. DISCUSSION

A lack of similarity between the seed mix and the resulting plant community in the first two growing seasons has been documented in other reclamation research

(Bush 1998, Howat 1998). Initial site conditions strongly influence plant community development (Wilson 1992), as exemplified by the performance of the seedbank in this research. These initial conditions are linked to competition among species for light, nutrients (Tilman 1982) and space, as seeded species attempt to germinate and establish in the same space and time as the seedbank species.

The first year plant community was a reflection of the influence of the initial site conditions and the portion of seeded species that had successfully competed with that influence. During and following the second growing season, the seeded species found their life history strategies more competitive and the resulting plant community more closely resembled the seed mix from which it originated. This supports Clements' (1916) theory of succession suggests that plant community development is a process of facilitation, through which each species modifies the environment and therefore makes it suitable for another to establish.

On average, five to six species were usually present in the first growing season, five to eight early in the second growing season and six to eight late in the second growing season. These results are supported by Howat (1998) who found, regardless of the species richness of the seed mix, the resulting vegetation community contained four or five main species. It was apparent that species densities were not equal; certain species had much higher densities than others while some species were absent. Clark (1998) also found disproportionate establishment occurred with many native species. Species present may represent key functional groups in the early stages of plant community development (Hooper and Vitousek 1997, Tilman et al. 1997).

The most common and successful seeded grasses and forbs had few traits in common (Appendix A), which does not suggest certain life history strategies are more successful than others. Instead, it suggests that a successful seeded community requires a variety of life history strategies, and emphasizes the importance functional group richness. The most abundant grasses had sod or bunch growth forms and reproduced by seeds or rhizomes. The most common forbs had mat or solitary growth forms and reproduced by seeds or rhizomes.

Bush (1998) concluded that seed mix diversity had no effect on percent cover or species density, and hypothesized that the ability of individual species to influence the plant community development was far more important (eg. Gill 1996, Hooper and Vitousek 1997, Tilman et al. 1997). The two most common species in the first and second year communities were fast growing, competitive wheatgrasses which undoubtedly influenced community development. However, far greater than the influence of seed mix richness or competitive seeded species was that of the seedbank (eg. Wilson 1992) which played a major role in the first two years of the development of this native plant community. Amongst the dominating influence of the seedbank, any effect related to seed mix or individual species may have been too slight to be visually or statistically noticeable. It is possible that such an effect may be more discernable in subsequent years.

Bush (1998) found that seed mix diversity had no effect on weed species composition or invasion. Stohlgren et al. (1999) concluded that invasion of non-seeded species is independent of species richness and may be related to resource availability. According to Tilman (1982), competition for limiting resources plays a major role in determining plant community composition.

Greater species richness was generally not associated with increased ground or canopy cover. A similar result was found by Bush (1998). Mix 3 produced the highest percent live vegetation and the least amount of bare ground in the first growing season. During the early second growing season, mix 1 produced the most live vegetation. Perhaps this moderate level of species richness provided just enough species to utilize a wide variety of resources and produce adequate vegetation biomass, but yet did not contain too many species that would cause intense competition and limit biomass production. The decreasing influence of management techniques, coupled with the increased influence of plant community development processes, may be the reason why this trend did not continue late in the second growing season.

7.0. MANAGEMENT IMPLICATIONS

Although there is a growing foundation of basic knowledge pertaining to the design and management of native seed mixes, it is not reasonable to assume sound research or management principles have been developed. Until such time, the scientific community and industry must act in accordance with ecological principles and common sense. All management decisions must consider not only scientific findings but also site conditions, the specific species seeded, financial constraints, the goals of the reclamation project and the end-land use.

Despite even the best management efforts during the first two years of plant community development, the community will likely be a juvenile interpretation of the mature community envisioned when the seed mix was designed. In this research, vegetative cover in the first year was composed mainly of seedbank species, with some dominant seeded species; most seeded species were not commonly present until the second growing season. However, the general appearance of the second year community reflected a more mature community; one with the promising presence of a variety of seeded grass and forb species and the less obtrusive presence of non-seeded species. This community may not meet the percent cover requirements and may not bear close resemblance to the adjacent land, as required by the 1999 Alberta Wellsite Criteria. Nevertheless, the community is of merit because it does provide ground cover, potentially reduce erosion and aid in soil development.

The need for a species rich plant community may not exist for all reclamation projects. Such a decision must consider the fundamental goals of the project and the legislation pertaining to it. Further study is needed to enable the reclamation industry to understand and appreciate the complexity, intricacy and perplexity of plant community development.

8.0. CONCLUSIONS

Seed mix richness had no effect on plant community species richness or on individual seeded species.

- Species richness in the plant community was not affected by number of species in the seed mix.
- Species richness of the seed mix did not affect seeded species density, percent biovolume or density-biovolume in the plant community.
- Seed mix richness did not have a significant effect on non-seeded species.
- Greater species richness of the seed mix was generally not associated with increased ground or canopy cover.
- *Agropyron dasystachyum*, *A. trachycaulum* and *Stipa viridula* were consistently present in the plant community. *Poa palustris* was consistently present in the second growing season.
- Most seeded forbs were present in the plant community by the end of the second growing season.
- *Achillea millefolium* and *Vicia americana* were present in the seedbank and/or the surrounding area and invaded in substantial numbers.

9.0. LITERATURE CITED

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Table 4.1. Mean density, biovolume and density-biovolume of common grasses in four mixes in July 1998 at Ellerslie and Tawayik Lake and Oster Lake, Elk Island National Park

	Density (plants m^{-2})				% Biovolume				Density-Biovolume			
Species Summation	Mix 1	Mix 2	Mix 3	Mix 4	Mix 1	Mix 2	Mix 3	Mix 4	Mix 1	Mix 2	Mix 3	Mix 4
Tawayik Lake												
Agropyron dasystachyum	3 [1]	2	3	2	2	0	2	0	2	1	4	0
	6 [2]	5	7	5	7	1	5	1	10	2	12	1
Agropyron trachycaulum	13	12	13	13	7	3	8	2	18	10	19	5
	14	13	12	14	12	5	12	4	42	19	39	9
Bouteloua gracilis	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	2	0	0	0	0	0	0	0	0	0
Festuca hallii	0 b	3 a	0 b	0 b	0 b	1 a	0 b	0 b	0 b	1 a	0 b	0 b
	0	5	0	0	0	1	0	0	0	1	0	0
Koeleria macrantha	0	1	0	0	0	0	0	0	0	0	0	0
	0	4	2	0	0	1	2	0	0	2	2	0
Stipa viridula	4	3	2	1	1	0	0	0	2	1	1	0
	7	7	4	3	3	1	1	0	6	3	2	0
Oster Lake												
Agropyron dasystachyum	3	1	2	2	2	0	0	1	2	0	0	1
	5	3	5	4	5	2	2	4	10	2	2	4
Agropyron trachycaulum	7	6	9	9	6	7	10	7	10	12	23	12
	9	7	12	11	10	15	20	11	24	35	57	21
Bouteloua gracilis	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	2	0	0	0	0	0	0	0	0

Table 4.1. Mean density, biovolume and density-biovolume of common grasses in four mixes in July 1998 at Ellerslie and Tawayik Lake and Oster Lake, Elk Island National Park (cont'd)

Species Summation	Density (plants m^{-2})				% Biovolume				Density-Biovolume			
	Mix 1	Mix 2	Mix 3	Mix 4	Mix 1	Mix 2	Mix 3	Mix 4	Mix 1	Mix 2	Mix 3	Mix 4
Oster Lake (cont'd)												
Festuca hallii	0	1	0	0	0	0	0	0	0	0	0	0
	0	2	0	0	0	1	0	0	0	1	0	0
Koeleria macrantha	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0	0
Stipa viridula	1	0	1	0	0	0	1	0	0	0	1	0
	3	2	3	2	1	1	4	0	1	1	4	0
Ellerslie												
Agropyron dasystachyum	2	1	2	2	3	2	4	3	3	2	6	2
	5	3	6	4	7	7	13	10	7	7	34	10
Agropyron trachycaulum	18 a	10 b	13 ac	10 bc	37 a	25 b	32 ac	24 bc	96	57	68	48
	16	12	12	13	35	36	32	30	128	100	99	75
Bouteloua gracilis	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	1	0	0	0	1	0	0	0	1
Festuca hallii	0	1	0	0	0	1	0	1	0	1	0	1
	0	3	0	2	0	6	0	6	0	6	0	11
Koeleria macrantha	0	0	0	0	0	0	0	1	0	0	0	1
	2	2	2	2	1	1	0	5	1	1	0	5
Stipa viridula	1	1	1	0	1	1	0	0	1	1	3	0
	4	4	2	2	3	6	2	1	3	3	2	1

[1] Mean, [2] Standard Deviation

Values in a row sharing same letter are not significantly different at $\alpha=0.05$; fill colour indicates values affected by season-mow*mix interaction

Table 4.2. Mean density, biovolume and density-biovolume of common grasses in four mixes in May 1999 at Ellerslie and Tawayik Lake and Oster Lake, Elk Island National Park

	Density (plants m^{-2})				% Biovolume				Density-Biovolume			
Species Summation	Mix 1	Mix 2	Mix 3	Mix 4	Mix 1	Mix 2	Mix 3	Mix 4	Mix 1	Mix 2	Mix 3	Mix 4
Tawayik Lake												
Agropyron dasystachyum	3[1]	5	5	1	0 b	5 a	2 b	0 b	1	7	4	1
	10[2]	9	12	4	1	13	7	2	3	18	21	4
Agropyron trachycaulum	23	20	14	20	34 a	20 b	23 b	24 b	103	76	50	100
	19	47	13	50	31	22	27	29	112	225	68	337
Bouteloua gracilis	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0	0
Festuca hallii	0 b	2 a	0 b	1 ab	0 b	3 a	0 b	1 b	0 b	4 a	0 b	1 b
	0	5	0	2	0	7	0	3	0	12	0	3
Koeleria macrantha	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0	0
Stipa viridula	1	1	1	0	0	1	0	0	1	1	0	0
	5	2	2	0	2	3	1	0	2	3	1	0
Oster Lake												
Agropyron dasystachyum	5	3	7	3	1 b	2 b	6 a	2 b	3	3	10	3
	14	6	10	7	2	5	16	5	10	11	24	9
Agropyron trachycaulum	17	12	12	13	42 a	35 ab	30 b	25 b	92 a	52 b	59 b	51 b
	13	8	11	12	30	28	29	25	96	56	71	66
Bouteloua gracilis	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0	0

Table 4.2. Mean density, biovolume and density-biovolume of common grasses in four mixes in May 1999 at Ellerslie and Tawayik Lake and Oster Lake, Elk Island National Park (cont'd)

	Density (plants m^{-2})				% Biovolume				Density-Biovolume			
Species Summation	Mix 1	Mix 2	Mix 3	Mix 4	Mix 1	Mix 2	Mix 3	Mix 4	Mix 1	Mix 2	Mix 3	Mix 4
Oster Lake (cont'd)												
Festuca hallii	0 b	2 a	0 b	1 ab	0 b	3 a	0 b	1 ab	0 b	3 a	0 b	1 ab
	0	5	0	4	0	9	0	2	0	9	0	4
Koeleria macrantha	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0	0
Stipa viridula	0	0	1	1	0	0	1	0	0	0	1	0
	0	2	3	2	0	1	5	2	0	1	5	2
Ellerslie												
Agropyron dasystachyum	4	3	4	4	4	3	5	4	9	7	10	10
	10	8	8	9	14	11	14	13	33	43	30	45
Agropyron trachycaulum	24 a	15 b	16 b	16 b	67 a	52 b	51 b	52 b	189 a	109 b	101 b	99 b
	35	22	17	11	30	36	35	31	337	158	103	90
Bouteloua gracilis	0	0	0	0	0	0	0	0	0	0	0	0
	0	1	0	0	0	2	0	0	0	2	0	0
Festuca hallii	0 b	2 a	0 b	1 a	0 b	5 a	0 b	2 ab	0 b	5 a	0 b	2 ab
	1	4	2	4	0	19	3	9	0	19	3	13
Koeleria macrantha	0	2	0	0	0	0	0	0	0	2	0	0
	2	10	0	3	1	2	0	0	1	10	0	0
Stipa viridula	1	1	2	1	2	2	4	1	3	2	4	1
	5	3	5	5	8	6	13	3	10	6	14	6

[1] Mean, [2] Standard Deviation

Values in a row sharing same letter are not significantly different at $\alpha=0.05$; fill colour indicates values affected by one or more two or three-way interactions

Table 4.3. Mean density, biovolume and density-biovolume of common grasses in four mixes in July 1999 at Ellerslie and Tawayik Lake and Oster Lake, Elk Island National Park

	Density (plants m^{-2})				% Biovolume				Density-Biovolume			
Species Summation	Mix 1	Mix 2	Mix 3	Mix 4	Mix 1	Mix 2	Mix 3	Mix 4	Mix 1	Mix 2	Mix 3	Mix 4
Tawayik Lake												
Agropyron dasystachyum	3 [1]	5	2	3	2	1	2	2	3	3	4	3
	7 [2]	10	5	6	4	3	10	7	8	11	20	13
Agropyron trachycaulum	16	19	19	19	51	53	54	45	91	113	124	111
	9	11	30	12	29	25	29	31	68	94	221	105
Bouteloua gracilis	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0	0
Festuca hallii	0 b	3 a	0 b	2 a	0 b	2 a	0 b	1 b	0 b	2 a	0 b	1 b
	0	5	2	5	0	4	0	1	0	6	0	2
Koeleria macrantha	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0	0
Stipa viridula	3	3	1	2	1	1	0	2	4	2	0	1
	9	8	2	5	4	4	0	7	16	5	0	3
Oster Lake												
Agropyron dasystachyum	2	7	4	3	2	2	2	1	2	7	6	2
	5	12	9	6	5	6	6	4	6	22	20	5
Agropyron trachycaulum	15	12	15	14	46	39	48	33	82	68	79	54
	9	9	7	8	29	35	28	27	69	73	60	54
Bouteloua gracilis	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0	0

Table 4.3. Mean density, biovolume and density-biovolume of common grasses in four mixes in July 1999 at Ellerslie and Tawayik Lake and Oster Lake, Elk Island National Park (cont'd)

	Density (plants m^{-2})				% Biovolume				Density-Biovolume			
Species Sum	Mix 1	Mix 2	Mix 3	Mix 4	Mix 1	Mix 2	Mix 3	Mix 4	Mix 1	Mix 2	Mix 3	Mix 4
Oster Lake (cont'd)												
Festuca hallii	0	1	0	0	0	0	0	0	0	0	0	0
	0	2	0	2	0	0	0	0	0	0	0	0
Koeleria macrantha	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0	0
Stipa viridula	2	1	1	1	1	0	0	0	1	1	0	0
	4	4	3	3	3	2	1	0	3	2	1	0
Ellerslie												
Agropyron dasystachyum	4 a	2 b	2 b	2 b	3 a	4 a	1 ab	1 b	5	4	1	1
	9	5	4	4	7	12	3	5	21	12	4	5
Agropyron trachycaulum	17 a	13 b	15 a	13 ab	78 a	72 a	64 b	55 c	138 a	108 b	108 b	86 b
	8	7	12	7	19	29	28	31	82	65	118	64
Bouteloua gracilis	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0	0
Festuca hallii	0 b	1 a	0 b	1 a	0	3	0	2	0	3	0	2
	1	3	1	3	1	15	1	9	1	15	1	9
Koeleria macrantha	0	0	0	0	0	0	0	0	0	0	0	0
	0	2	1	2	0	1	0	0	0	1	0	0
Stipa viridula	2	2	1	1	1	3	2	1	1	3	2	1
	4	5	3	3	3	9	7	4	3	9	7	4

[1] Mean, [2] Standard Deviation

Values in a row sharing same letter are not significantly different at $\alpha=0.05$; fill colour indicates values affected by one or more two or three-way interactions

Table 4.4. Mean density, biovolume and density-biovolume of non-seeded species in four mixes in July 1998 at Ellerslie and Tawayik Lake and Oster Lake, Elk Island National Park

	Density (plants m^{-2})				% Biovolume				Density-Biovolume			
Species Summation	Mix 1	Mix 2	Mix 3	Mix 4	Mix 1	Mix 2	Mix 3	Mix 4	Mix 1	Mix 2	Mix 3	Mix 4
Tawayik Lake												
Non-seeded species	296 [1]	331	275	318	888	918	881	964	11344 b	16762 a	10383 b	13507 b
	156 [2]	131	160	153	166	118	179	45	9508	14434	13323	12898
Non-seeded grasses	10	19	14	13	10	35	10	6	18	209	16	16
	13	26	26	21	22	112	18	7	71	827	31	33
Non-seeded forbs	286	312	261	305	878	884	871	958	11326 b	16553 a	10367 b	13491 b
	154	137	151	143	170	166	182	48	9517	14610	13328	12897
Oster Lake												
Non-seeded species	114	92	95	117	908	906	829	878	2655	2364	2914	2536
	47	35	50	50	139	148	264	146	2769	1436	2199	1460
Non-seeded grasses	0 a	1 a	1 a	1 b	4	0	1	15	0	0	1	29
	2	5	2	10	23	0	5	73	0	0	5	145
Non-seeded forbs	114	91	95	112	904	906	828	864	2655	2364	2913	2507
	48	34	50	46	140	148	266	157	2769	1436	2200	1481
Ellerslie												
Non-seeded species	58 a	52 a	55 a	40 b	577 b	698 ac	573 b	664 bc	1235 ab	1620 a	1142b b	1071 b
	69	45	38	24	369	380	354	340	1901	2060	1344	857
Non-seeded grasses	2	3	3	3	6	30	8	40	5	89	5	55
	4	6	7	6	21	137	22	164	18	556	16	254
Non-seeded forbs	57 a	49 a	52 a	37 b	571	667	565	626	1229 b	1531 a	1137 b	1016 b
	69	45	38	23	370	393	351	346	1903	2047	1344	869

[1] Mean, [2] Standard Deviation

Values in a row sharing same letter are not significantly different at $\alpha=0.05$; fill colour indicates values affected by season-mow*mix interaction

Table 4.5. Mean density, biovolume and density-biovolume of non-seeded species in four mixes in May 1999 at Ellerslie and Tawayik Lake and Oster Lake, Elk Island National Park

	Density (plants m^{-2})				% Biovolume				Density-Biovolume			
Species Summation	Mix 1	Mix 2	Mix 3	Mix 4	Mix 1	Mix 2	Mix 3	Mix 4	Mix 1	Mix 2	Mix 3	Mix 4
Tawayik Lake												
Non-seeded species	569 [1]	507	614	546	65	70	72	73	742	687	725	985
	307 [2]	242	319	288	31	23	28	30	592	615	467	711
Non-seeded grasses	28	38	64	33	1	3	2	4	6	15	8	13
	43	95	100	38	2	7	2	8	12	49	10	25
Non-seeded forbs	540	469	550	514	64	67	70	69	737	672	717	973
	283	219	269	281	32	23	28	29	595	623	466	708
Oster Lake												
Non-seeded species	339	354	322	308	52	52	56	57	329	460	284	459
	320	254	207	224	32	24	28	26	422	795	354	714
Non-seeded grasses	9	10	9	7	1	4	3	3	1	9	8	5
	19	17	15	12	2	9	7	6	2	29	23	15
Non-seeded forbs	330	344	313	301	51	48	53	55	327	451	276	455
	312	256	200	225	32	23	26	25	422	798	353	715
Ellerslie												
Non-seeded species	469	468	454	481	25	32	28	30	138	227	196	148
	225	229	217	273	25	33	30	24	137	440	408	149
Non-seeded grasses	91	91	67	82	4	3	6	5	26	16	25	24
	137	136	96	120	10	10	15	13	67	31	64	55
Non-seeded forbs	378	377	387	399	22	30	22	25	111	211	171	124
	180	173	206	236	23	31	27	23	120	440	408	132

[1] Mean, [2] Standard Deviation

Values in each row sharing same letter are not significantly different at α=0.05; fill colour indicates values affected by one or more two or three-way interactions

Table 4.6. **Mean density, biovolume and density-biovolume of non-seeded species in four mixes in July 1999 at Ellerslie and Tawayik Lake and Oster Lake, Elk Island National Park**

	Density (plants m^{-2})				% Biovolume				Density-Biovolume			
Species Summation	Mix 1	Mix 2	Mix 3	Mix 4	Mix 1	Mix 2	Mix 3	Mix 4	Mix 1	Mix 2	Mix 3	Mix 4
Tawayik Lake												
Non-seeded species	508 [1]	540	494	483	45	37	40	47	438 a	230 b	261 b	277 b
	182 [2]	184	185	172	30	26	28	33	516	167	279	239
Non-seeded grasses	24 b	52 a	27 b	35 a	4	2	6	4	15	12	20	8
	25	79	28	40	6	3	7	7	27	29	35	11
Non-seeded forbs	484	488	467	448	41	35	34	43	423 a	218 b	241 b	268 b
	181	168	181	162	31	35	25	33	521	166	277	240
Oster Lake												
Non-seeded species	143	153	133	153	46	54	42	51	211	180	139	266
	117	99	93	110	29	33	23	29	253	156	134	564
Non-seeded grasses	3 b	16 a	9 b	7 b	2	3	4	2	2	11	8	3
	5	29	13	10	7	7	10	3	7	37	18	9
Non-seeded forbs	141	137	125	146	44	51	38	49	208	169	131	262
	118	91	91	110	29	31	23	28	254	151	134	564
Ellerslie												
Non-seeded species	355	332	382	370	17	15	16	18	59	65	70	65
	203	180	197	201	19	16	20	19	39	62	73	49
Non-seeded grasses	13	4	10	11	2 a	0 b	0 b	1 b	4	1	1	4
	30	13	57	34	8	2	1	6	10	2	6	15
Non-seeded forbs	342	328	372	360	15	14	16	16	55	65	68	62
	193	180	183	197	17	16	20	18	39	62	72	48

[1] Mean, [2] Standard Deviation

Values in each row sharing same letter are not significantly different at α=0.05; fill colour indicates values affected by one or more two or three-way interactions

Table 4.7. Mean percent ground and canopy cover in four seed mixes in July 1998 at Ellerslie and Tawayik Lake and Oster Lake, Elk Island National Park

Parameter	Mix 1	Mix 2	Mix 3	Mix 4
Tawayik Lake				
% Live vegetation	7.4 [1]b	4.3 b	12.0 a	4.7 b
	7.0 [2]	2.6	15.3	2.7
% Bare ground	92.6 a	95.7 a	88.0 b	95.4 a
	7.0	2.6	15.3	2.7
% Live canopy	86.5 a	88.2 a	81.9 b	95.0 a
	17.1	22.6	20.3	8.2
% Dead canopy	0.5 b	0.1 b	6.3 a	1.3 b
	2.2	0.4	18.3	4.9
Oster Lake				
% Live vegetation	3.7	4.1	5.2	4.2
	1.9	3.2	3.4	3.5
% Bare ground	96.3	95.9	94.8	95.8
	1.9	3.2	3.4	3.5
% Live canopy	72.9	62.4	65.9	73.0
	25.5	27.9	33.8	29.2
% Dead canopy	0.5	0.1	0.4	0.4
	1.6	0.5	1.6	0.9
Ellerslie				
% Live vegetation	2.2 bc	2.4 c	2.9 a	2.3 b
	1.9	2.2	1.8	1.6
% Bare ground	97.8 a	97.3 b	97.1 b	97.7 a
	1.9	2.7	1.8	1.6
% Live canopy	21.4 ab	17.5 b	24.6 a	21.0 ab
	23.9	19.1	21.6	21.0
% Dead canopy	6.5	4.8	7.1	5.6
	10.2	9.7	10.7	9.2

[1] Mean, [2] Standard Deviation

Values in a row sharing same letter are not significantly different at $\alpha=0.05$

Fill colour indicates values affected by season-mow*mix interaction

Table 4.8. Mean percent ground and canopy cover in four seed mixes in May 1999 at Ellerslie and Tawayik Lake and Oster Lake, Elk Island National Park

Parameter	Mix 1	Mix 2	Mix 3	Mix 4
Tawayik Lake				
% Live vegetation	45.4 [1]a	32.4 b	28.0 b	42.8 a
	30.9 [2]	22.8	19.7	22.6
% Litter	26.1	33.4	24.7	23.3
	26.5	29.4	25.4	21.5
% Bare ground	27.4	33.6	37.0	33.8
	24.8	25.4	25.1	25.3
% Moss	1.2	0.7	0.4	0.2
	4.8	1.5	1.0	0.7
% Live canopy	77.2	79.2	82.0	77.5
	21.1	21.2	19.2	20.9
% Dead canopy	20.1	15.4	14.0	20.5
	20.3	15.7	14.3	21.3
Oster Lake				
% Live vegetation	21.4 a	17.8 ab	11.6 b	14.3 b
	17.0	13.6	11.3	10.7
% Litter	42.8 a	30.1 b	53.2 a	24.7 b
	33.6	31.6	34.7	26.6
% Bare ground	34.1 b	48.0 ab	33.2 b	59.4 a
	32.9	29.2	34.2	30.3
% Moss	1.7	4.2	2.0	1.7
	2.8	13.5	3.2	2.8
% Live canopy	84.4	76.6	80.8	83.2
	16.3	22.0	15.6	14.9
% Dead canopy	10.5	11.4	13.5	10.5
	12.7	10.7	11.9	11.6
Ellerslie				
% Live vegetation	18.2 a	14.0 b	15.8 a	11.3 b
	15.9	13.3	14.3	9.3
% Litter	27.6	26.1	22.1	28.8
	25.7	26.9	19.2	27.5
% Bare ground	52.3 b	59.4 a	61.2 a	57.4 a
	29.3	31.9	27.3	29.8
% Moss	1.9	0.6	0.9	2.5
	3.6	1.4	2.1	6.9
% Live canopy	50.8	53.2	50.0	55.1
	20.3	21.8	21.1	20.0
% Dead canopy	24.6	19.3	21.1	19.1
	17.1	15.9	16.1	17.2

[1] Mean, [2] Standard Deviation

Values sharing same letter are not significantly different at α=0.05

Fill colour indicates values affected by one or more two or three-way interactions

Table 4.9. Mean percent ground and canopy cover in four seed mixes in July 1999 at Ellerslie and Tawayik Lake and Oster Lake, Elk Island National Park

Parameter	Mix 1	Mix 2	Mix 3	Mix 4
Tawayik Lake				
% Live vegetation	15.6[1] b	11.4 b	22.7 a	14.4 b
	14.0[2]	8.9	21.5	12.3
% Litter	57.5	54.8	51.8	59.8
	30.4	35.3	31.3	29.2
% Bare ground	25.6	33.8	24.8	25.8
	25.7	34.0	26.2	25.7
% Moss	1.3	0.0	0.8	0.0
	4.4	0.0	4.7	0.2
% Live canopy	72.0	79.7	74.8	79.4
	20.0	16.2	23.5	18.3
% Dead canopy	24.6	16.4	19.5	17.8
	18.0	13.4	18.7	17.7
Oster Lake				
% Live vegetation	9.3	11.1	10.6	11.9
	4.0	6.5	6.8	7.6
% Litter	55.5	51.3	49.5	51.8
	29.6	23.7	33.5	26.5
% Bare ground	31.9	35.6	38.2	35.1
	26.8	22.5	30.9	23.2
% Moss	3.4	2.2	1.8	1.3
	9.5	4.3	2.8	2.9
% Live canopy	88.4	89.4	89.9	93.0
	12.4	10.4	8.5	7.3
% Dead canopy	9.7	9.1	6.7	6.3
	9.2	8.4	5.3	6.7
Ellerslie				
% Live vegetation	12.2	13.6	12.3	13.2
	6.9	8.3	6.2	7.6
% Litter	13.3	13.0	9.9	7.7
	22.3	21.1	13.7	11.6
% Bare ground	67.1	67.5	72.5	71.7
	26.4	23.5	18.3	16.7
% Moss	7.5	5.9	5.3	7.5
	11.8	11.1	6.6	10.4
% Live canopy	45.0	46.7	50.2	41.9
	29.4	25.7	26.7	24.3
% Dead canopy	24.3	19.7	21.5	18.5
	19.7	13.7	16.2	14.2

[1] Mean, [2] Standard Deviation

Values in each row sharing same letter are not significantly different at α=0.05

Fill colour indicates values affected by one or more two or three-way interactions

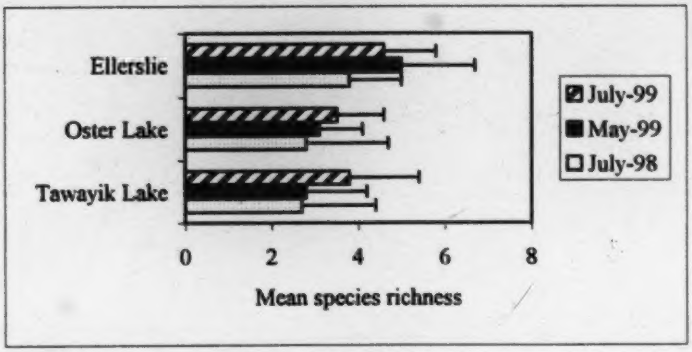

Figure 4.1. Mean seeded grass species richness

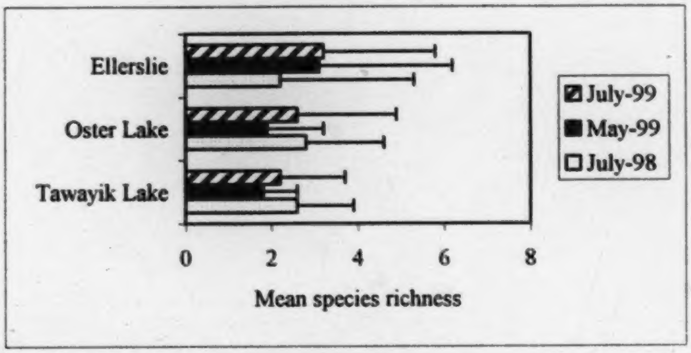

Figure 4.2. Mean seeded forb species richness

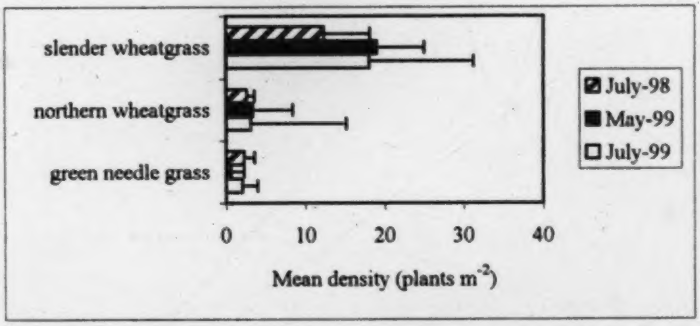

Figure 4.3. Mean density of common seeded grasses at Tawayik Lake

[1] Error bars indicate standard deviation

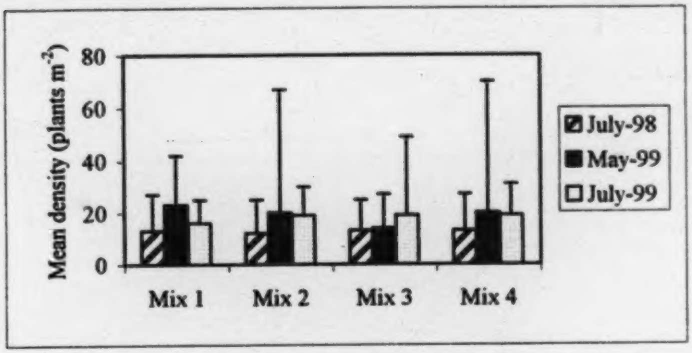

Figure 4.4. Mean density of slender wheatgrass at Tawayik Lake

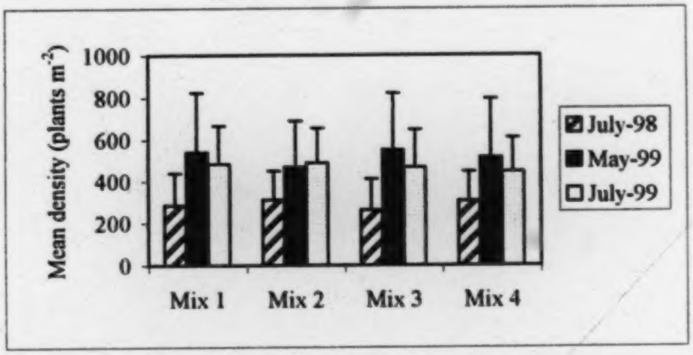

Figure 4.5. Mean density of non-seeded forbs at Tawayik Lake

[1] Error bars indicate standard deviation

CHAPTER V. SYNTHESIS

1.0. SUMMARY OF RESULTS

After the first year growing season, the spring seeded treatment had higher seeded and generally lower non-seeded species density, percent biovolume and density-biovolume than the fall seeded treatment. Ground and canopy cover was not affected by season of seeding. Early in the second year, the density of both seeded and non-seeded species was generally higher in spring than fall seeded treatments. The percent biovolume and density-biovolume of the seeded species was still higher in the spring and non-seeded species lower than in the fall seeded treatment. Ground and canopy cover remained unaffected by season of seeding. Late in the second growing season, the density, biovolume and density-biovolume of all species and seeded grasses were higher in spring than fall seeded treatments. The biovolume and density-biovolume of non-seeded species and non-seeded forbs were higher in fall than spring seeded treatments. Ground and canopy cover remained unaffected by season of seeding, with the exception of live canopy cover, which was higher in fall than spring seeded treatments.

In the first year, mowing increased the density, biovolume and density-biovolume of seeded species, and decreased the biovolume of non-seeded species and bare ground. Early in the second growing season, mowing no longer affected seeded plant density, biovolume or density biovolume, was associated with lower density and higher density-biovolume of non-seeded species and had no effect on non-seeded species biovolume. The difference in ground cover and canopy cover between mowing treatments became more apparent; mowing had more litter, less bare ground, more live canopy and less dead canopy than the unmowed treatment. Late in the second growing season, seeded and non-seeded species were not affected by mowing. Live canopy was higher under mow than unmow treatments and was statistically significant at two sites. Litter, bare ground, live and dead canopy were no longer affected by mowing. Moss cover was higher in the mow than the unmow treatment.

After the first and second growing season, it was apparent that what was seeded was not exactly what was present in the plant community. There was a significant decrease in the species richness of grasses present versus seeded; there was a non-significant decrease for forbs. On average, five to six species were present in the first year community, while five to eight species were present early in the second year and six to eight were present late in the second year. The richness of species in the community did not increase with a greater number of species in the seed mix. Species richness of the seed mix did not affect density, biovolume or density-biovolume of the six grasses common to the four mixes, density, biovolume or density-biovolume of non-seeded species or ground or canopy cover.

2.0. MANAGEMENT IMPLICATIONS

Although seeding in the spring may increase the potential for successful seeded native plant community development in the Aspen Parkland, the choice of seeding season should also consider site access and life history strategies of the species to be seeded.

Mowing will increase the likelihood of seeded species success, while reducing the biovolume of potential competitors, during the first growing season. However, mowing may be detrimental if conducted too early or at an inappropriate height. Accessing remote sites with a mower may be expensive or unfeasible.

Despite the best management efforts during the first two years of plant community development, the community will likely be a juvenile interpretation of the mature community envisioned when the seed mix was designed. The need for a species rich plant community may not exist for all reclamation projects.

3.0. FUTURE RESEARCH

This research generated several questions to be pursued. What is the role of early spring soil moisture conditions in native plant community development and how can favorable soil moisture conditions be quantified? What is (are) suitable timing(s) of mowing treatments for the purpose of controlling non-seeded species in native vegetation? Does the seed mix have any influence in the development of the plant community beyond the first two growing seasons?

Long term research is needed to study the season of seeding, mowing and seed mix richness in plant community development. If recommendations for changes to reclamation practises or legislation are to be made, there must be a better understanding of what occurs beyond the first two years of plant community development. This information may be important for suggesting changes to percent cover requirements as they currently exist in the 1999 Alberta Wellsite Criteria. It is difficult to state with certainty that spring seeding is preferred, that mowing has no effect beyond the first year, or that the seed mix has no effect on the composition or species richness of the plant community, without the knowledge of what processes and developments occur after the first two growing seasons.

Although chemical or mechanical control of seedbank species may contravene theories of plant community development, "weed management" is a common practice in the reclamation industry. Future studies might focus on the long-term role of seedbank contributions in native plant community development and, potentially, methods of controlling such species.

The main weakness in ecological fieldwork is the degree of environmental variability influencing treatment effects. Indeed, "background noise" does make it difficult to state with certainty the true effect of a given treatment. Connell (1983a, 1993b) describes how indirect effects make it difficult to say with certainty that a given mechanism is responsible for an observed pattern, considering the difficulty associated with field experiments. However, such is the nature of an applied science such as land reclamation. Similar studies conducted in a laboratory or greenhouse setting would have limited applicability in the field. Future research findings would be more credible if environmental variability could be quantified statistically.

4.0. RESEARCH REVELATIONS

Beyond achieving research objectives and providing implications for reclamation managers, this research questions several commonly held beliefs that are often based on observation instead of scientific research.

In the reclamation industry, the rule of thumb for seeding rate is usually 250 to 300 seeds m^{-2}. While the chosen rate of 200 m^{-2} may seem low to some practitioners, it did allow for a balance between success of seeded species and invasion of non-seeded species from the seedbank and adjacent area. While this lower seeding rate is not recommended for all sites, it is an economical and viable alternative to standard seeding rates.

Because equipment limitations did not allow for multiple seeding depths, all grass seeds were drill seeded to a depth of 2.5 cm. Ideally, the grasses should have been seeded according to the seed size of each species (Vallentine 1989), at depths sufficient to take advantage of favorable soil moisture conditions, but not so deep that seedling emergence and vigour were reduced (Fulbright et al. 1985). However, because all grasses were seeded at this depth, the smaller seeded species may have been seeded too deep. The consequence of seeding too deep is usually poor germination, reduction in total emergence and the rate of emergence (Plummer 1943, McGinnies 1960, Kilcher and Lawrence 1970, Fulbright et al. 1985, Maun and Lapierre 1986, Lodge and Schipp 1993, Pickering and Raju 1996) and reduction in seedling vigour (Mutz and Scifres 1975).

The seed size was quite variable, from small *Agrostis stolonifera* and *Bouteloua gracilis* seeds, to large *Agropyron* seeds. However, during the first two growing seasons, all grass species were eventually present (note specific measurements of germination, emergence or vigour were not taken). This is impressive, especially for the smaller seeded species. It is interesting that *B. gracilis* grew at a location at or beyond the northern reaches of its perceived range. Blue grama is also unique because it is a warm season species while the majority of species common to the Aspen Parkland are cool season species.

Early in this research, there was speculation that forb seed would not establish successfully because the seed was not harrowed (due to weather restrictions). However, all species were present at some point during the first two growing seasons. Many species grew to a significant size and even produced seed. This indicates harrowing may not be as necessary.

Non-seeded species were present throughout this research. Despite an aggressive program of herbicide and cultivation for months prior to seeding, the seedbank still produced a tremendous crop of non-seeded species. Thus preparation before seeding is just as important as the seeding and management.

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APPENDIX A. SPECIES LIST AND LIFE HISTORY CHARACTERISTICS

A. LIFE HISTORY STRATEGIES

A.1. *Agropyron dasystachyum*

Agropyron dasystachyum (Hook.) Scribn. (northern wheatgrass) is widely distributed throughout the prairies. It is a cool season perennial with a creeping, sod forming root system. This aggressive root system is composed of shallow rhizomes and deeper fibrous roots (Wasser 1982). Northern wheatgrass plants grow in tufts to heights of 40 to 130 cm (Gerling et al. 1996). Although it is adapted to a wide range of soil conditions, northern wheatgrass prefers dry soils and has excellent drought tolerance. The combination of root types is thought to increase the drought tolerance as well as resistance to weed invasion (Looman 1983). Seedling vigour is excellent and establishment is considered easy (Thornburg 1982). Northern wheatgrass is relatively intolerant of shade, compatible with other species and has excellent germination and early spring growth. It is a cool season species; thus, the photosynthetic pathway is C_3. Northern wheatgrass is a long lived species, found in both early and late successional stages. This wheatgrass is suitable for seeding in fall or spring, to a depth of 2.5 cm (Wasser 1982).

A.2. *Agropyron trachycaulum var. trachycaulum*

Agropyron trachycaulum (Link) Malte *var. trachycaulum* (slender wheatgrass) is found throughout western North America. It is a tufted bunchgrass with a dense root system which extends to a depth of 50 cm (Looman 1983). Although technically a bunchgrass, this species is somewhat rhizomatous. Slender wheatgrass grows to a height of 50 to 150 cm (Gerling et al. 1996) and is shade tolerant. Seeds of this species generally have high germination and emergence rates, and seedlings are quite vigorous. Slender wheatgrass is a good competitor in the first two or three years because of its ability to rapidly establish, spread and produce seed. Slender wheatgrass also contributes large amounts of biomass to the soil. However, it is relatively short lived and tends to die off after a few years. This cool season wheatgrass is noted to have good winter hardiness but low drought resistance. Seeding is recommended in early summer or fall.

A.3. *Agrostis stolonifera*

Agrostis stolonifera L. (redtop) is introduced from Europe and is widely naturalized in North America (Wasser 1982, Stubbendieck et al. 1992). This sod forming grass has a shallow rhizomatous root system (Looman 1983). Redtop grows to a height ranging from 20 to 150 cm (Stubbendieck et al. 1992). Although it can tolerate a wide range of soil conditions, redtop thrives on moist to semiwet sites (Wasser 1982). It is tolerant of flooding, soil acidity and salinity and has good winter hardiness. Redtop is commonly seeded as a cool season pasture species and is moderately competitive (Wasser 1982). Redtop exhibits phytotoxic allelopathy and, when present in large proportions, can create difficulty in establishing grass mixes (Gussin and Lynch 1981). Wasser (1982) recommends seeding at 1.3 cm.

A.4. *Bouteloua gracilis*

Bouteloua gracilis (H.B.K.) Lag. (blue grama grass) is a densely tufted bunchgrass that forms a sod by means of creeping growth (Thornburg 1982, Wasser 1982). The surface roots extend down approximately 50 cm, while secondary roots may reach 1 m in depth (Looman 1983). It is a short species, rarely growing taller than 40 cm (Gerling et al. 1996). According to Coupland (1950), blue grama grass is "the only shortgrass of importance in Canada". It is the only warm season (C_4) grass and the only grass that reproduces mainly by tillers used in this research. It is fairly drought resistant and is commonly found on dry sites (Coupland 1950). Wasser (1982) reported blue grama has the unique ability to become semidormant with increasing drought; renewing growth quickly with available moisture. According to Gerling et al. (1996) it is relatively shade intolerant and is found in the later stages of succession. Bokhari (1978) found blue grama exhibited phytotoxic and autotoxic allelopathy. Wasser (1982) recommends seeding up to 1.3 cm.

Blue grama is difficult to establish from seed in areas where it is an ecological dominant (Hyder et al. 1971). The use of blue grama for revegetation in the Central Plains is limited because of difficulties in its establishment from seed (Wilson and Briske 1979). Attempts to plant blue grama have seldom been successful (Bement et al. 1965, Hyder et al. 1971). The largest difficulty in establishing blue grama may be due to seedling type. Panicoid seedlings, such as blue grama, have a short coleoptile elevated to the soil surface through elongation of the subcoleoptile internode. The Panicoid form places the coleoptilar node and adventitious roots at or near the soil surface. At this depth, the soil is dry except during or immediately after rain.

Usually, death of seedlings occurs because the adventitious roots do not grow out of the dry surface soil. Adventitious roots only grow from the tillering crowns when damp weather persists for 2 to 4 days (Wilson and Briske 1979). The adventitious roots are critical to the survival of the young plants (Esau 1960); blue grama seedlings die at 6 to 8 weeks of age unless adventitious roots are extended (Weaver and Zink 1945).

Other difficulties contribute to the difficulties encountered in establishing blue grama. They include low seed weight and a limited capacity for water uptake by the seminal root (Wilson et al. 1976). Wilson and Briske (1979) found establishment also requires average soil temperatures above 15°C and a soil water potential of –0.3 bars in the 0 to 40 cm zone at the time of emergence.

A.5. *Bromus carinatus*

Bromus carinatus Hook. & Arn. (mountain brome grass) is found in the Rocky Mountain, Intermountain and Pacific coast regions of western North America. Mountain brome grass is a bunchgrass that grows to a height ranging from 60 to 120 cm. The root system is deep and well branched. It is a rapidly developing but short-lived, cool season perennial. Mountain brome grass is found in the early stages of plant community succession. This brome will tolerate shade but prefers full sunlight. It has good seedling vigour (Thornburg 1982) and is considered to be moderately aggressive but compatible with other species. Seeding in late spring is recommended, to depths of up to 3.8 cm (Wasser 1982).

A.6. *Festuca hallii*

Festuca hallii (Vasey) Piper (plains rough fescue) is a densely tufted, low growing bunchgrass. Plains rough fescue is much shorter than the foothills variety which grows in the mountains of southern Alberta. Plains rough fescue is the community dominant in open patches in the Aspen Parkland (Moss 1955). It is a cool season species that reproduces by short rhizomes. It is found in both early and late successional stages.

A.7. *Festuca ovina*

Festuca ovina L. (sheep fescue) is native to North America, although some varieties have been introduced from Eurasia. It is a densely tufted bunchgrass, averaging 15 and 60 cm tall. Some populations of sheep fescue have rhizosheaths which fix atmospheric nitrogen; however, this trait is not a general species characteristic. This fescue is a long lived, cool season perennial. It reproduces from seed and has excellent winter hardiness. Sheep fescue is tolerant of shade, drought and low nutrient conditions. It is slow and difficult to establish (Plummer 1943) and rated as weakly aggressive. It may be seeded in fall or spring.

A.8. *Koeleria macrantha*

Koeleria macrantha (Ledeb.) Schult. (June grass) is one of the most widely distributed grasses in North America (Coupland 1950). It is a low growing tufted bunchgrass that often occurs as a single plant, rather than in dense stands (Looman 1983). The fibrous root system is shallow (10 to 20 cm) but dense (Looman 1983). Only a few deep roots extend to a depth of 120 cm (Looman 1983). June grass is a cool season perennial that is long lived. It can be found in both early and late successional stages. June grass flowers early in the summer, beginning when it is two or three years old. It reproduces by seed. Although it is usually found in open areas, it will tolerate shade. June grass is a moderately aggressive species.

A.9. *Poa palustris*

Poa palustris L. (fowl bluegrass) is a bunchgrass 30 to 100 cm tall (Gerling et al. 1996). This cool season grass reproduces by seed and is found in early successional stages.

A.10. *Stipa viridula*

Stipa viridula Trin. (green needle grass) is a long lived cool season grass, found in the southern portion of the prairies and the western United States. It is a tall, tufted bunchgrass. The root system is fibrous and deep (2 to 3 m) (Looman 1983). Like June grass, this species begins to flower in its third growing season. This grass reproduces by seed and is found in the earlier stages of succession. It is relatively intolerant of shade and has good drought tolerance (Wasser 1982). Green needle grass is moderately aggressive yet compatible with other species. Typically, seed of green needle grass has a high percent dormancy. Both fall and spring seeding is suitable for this grass (Gerling et al. 1996). Wasser (1982) recommends a depth of 2.5 cm.

A.11. *Achillea millefolium*

Achillea millefolium L. (common yarrow) originated in western North America and has since been introduced to several continents (Warwick and Black 1982). It grows in a mat and reaches heights of 30 to 80 cm (Gerling et al. 1996). It is a cool season forb with a shallow, fibrous root system and extensive rhizomes (Wasser 1982). Yarrow is commonly found in grasslands and open woods in the earlier stages of succession. Wasser (1982) reports it has moderate tolerance to shade. It also has an active symbiotic mycorrhizal association (Gerling et al. 1996). Yarrow is a drought tolerant species and is able to survive long dry periods (Dabrowska 1977). It is persistent to disturbance (Higgins and Mack 1987) and is competitive when established (Wasser 1982, Bourdot et al. 1984).

A.12. *Aster laevis*

Aster laevis L. (smooth aster) grows in moist grasslands and open forests. It has a solitary growth form and reaches heights of 40 to 100 cm (Gerling et al. 1996). It is one of six warm season forbs used in this research. This forb reproduces by rhizomes and is found in both early and late successional stages.

A.13. *Gaillardia aristata*

Gaillardia aristata Pursh. (gaillardia or blanket flower) is a solitary forb, 30 to 60 cm tall (Gerling et al. 1996). This forb is drought tolerant and can be found in dry areas including grasslands and roadsides (Gerling et al. 1996). It reproduces by seed and is an early successional species. Gaillardia is a cool season forb.

A.14. *Linum lewisii*

Linum lewisii Pursh. (wild blue flax) is another solitary forb. It has a woody perennial taproot (Wasser 1982) and may grow to a height of 20 to 70 cm (Gerling et al. 1996). This flax is a fairly competitive species and reproduces by seed. It is a cool season species found in early successional stages. It has an active mycorrhizal association (Gerling et al. 1996), it is drought tolerant and common in dry areas. Fisher et al. (1987) found wild blue flax difficult to establish, although stand establishment ratings were higher for fall seedings than spring.

A.15. *Monarda fistulosa*

Monarda fistulosa L. (horse mint) is a solitary forb, 30 to 70 cm tall (Gerling et al. 1996). It is commonly found in mesic sites, including open woods and fields. This warm season species reproduces by rhizomes. It is found in early successional stages of community development.

A.16. *Petalostemon purpureum*

Petalostemon purpureum (Vent.) Rydb. (purple prairie clover) is a solitary forb with a woody taproot (Thornburg 1982), growing 30 to 80 cm tall (Gerling et al. 1996). Although found on a wide variety of soils, it is most common on well drained sites (Wasser 1982). Drought tolerance is moderate, although shade tolerance is fair (Wasser 1982). It reproduces by seed and is found in both early and late successional stages. Purple prairie clover is a warm season species.

A.17. *Ratibida columnifera*

Ratibida columnifera (Nutt.) Woot. & Standl. (prairie cone flower) grows 30 to 50 cm with a solitary growth form (Gerling et al. 1996). Reproduction is by seed. This warm season species is found in early successional stages of dry to mesic grasslands. It has an active mycorrhizal association (Gerling et al. 1996).

A.18. *Solidago canadensis*

Solidago canadensis L. (Canada goldenrod) has a solitary growth form and reaches heights of 30 to 100 cm (Gerling et al. 1996). It is an early successional species that reproduces by rhizomes. Canada goldenrod is a warm season species commonly found in moist open meadows and grasslands.

A.19. *Solidago missouriensis*

Solidago missouriensis Nutt. (Low goldenrod) is a solitary forb, 10 to 60 cm tall (Gerling et al. 1996). The root system is fairly superficial, mostly short rhizomes (Wasser 1982). It is a common warm season species in mesic or dry sites in early successional stages. It has moderate tolerance for drought and shade and is a weak competitor (Wasser 1982).

A.20. *Vicia americana*

Vicia americana Muhl. ex. Willd. (American vetch) is an aggressive, solitary species. It has shallow to moderately deep rooted taproots and spreading rhizomes (Wasser 1982). This common species is found in a wide variety of habitats throughout the prairies, and is usually more abundant in deep soils that are rich in organic matter (Wasser 1982). It reaches heights of 30 to 100 cm and is found in both early and late successional stages (Gerling et al. 1996). It reproduces by seed and has the ability to fix atmospheric nitrogen. It is a cool season species that can tolerate full shade.

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Table A.1. Attributes of species used in four seed mixes

Scientific name	Growth form	Height (m)	Reproduction	Physiology	Seral stage
Grasses					
Agropyron dasystachyum	sod	0.4 to 1.3	rhizomes	cool	early/late
Agropyron trachycaulum	bunch	0.5 to 1.5	rhizomes	cool	late
Agrostis stolonifera	sod	0.2 to 1.5	rhizomes	cool	
Bouteloua gracilis	bunch	0.1 to 0.4	tillers	warm	late
Bromus carinatus	bunch	0.6 to 1.2	seeds	cool	early
Festuca hallii	bunch	0.2 to 0.6	rhizomes	cool	early/late
Festuca ovina	bunch	0.2 to 0.6	seeds	cool	
Koeleria macrantha	bunch	0.2 to 0.5	seeds	cool	early/late
Poa palustris	bunch	0.3 to 1.0	seeds	cool	early
Stipa viridula	bunch	0.4 to 0.8	seeds	cool	early
Forbs					
Achillea millefolium	mat	0.3 to 0.8	rhizomes	cool	early
Aster laevis	solitary	0.4 to 1.0	rhizomes	warm	early/late
Gaillardia aristata	solitary	0.3 to 0.6	seeds	cool	early
Linum lewisii	solitary	0.2 to 0.7	seeds	cool	early
Monarda fistulosa	solitary	0.3 to 0.7	rhizomes	warm	early
Petalostemon purpureum	solitary	0.3 to 0.8	seeds	warm	early/late
Ratibida columnifera	solitary	0.3 to 0.5	seeds	warm	early
Solidago canadensis	solitary	0.3 to 1.0	rhizomes	warm	early
Solidago missouriensis	solitary	0.1 to 0.6	rhizomes	warm	early
Vicia americana	solitary	0.3 to 1.0	seeds	cool	early/late

APPENDIX B. SEED MIX CALCULATIONS AND SUPPLEMENTAL SEEDING INFORMATION

Table B.1. Seed mix calculations[1] for four mixes seeded at Ellerslie and Tawayik Lake and Oster Lake, Elk Island National Park

Mix 1

Species	% PLS	Ratio	PLS kg^{-1}	g plot^{-1}	g row^{-1}
Agropyron dasystachyum	95	0.17	334	11.70	0.29
Agropyron trachycaulum	89	0.17	284	14.69	0.37
Bouteloua gracilis	67	0.17	2246	2.47	0.06
Festuca hallii	72	0.17	747	6.90	0.17
Koeleria macrantha	76	0.17	4195	1.16	0.03
Stipa viridula	65	0.17	630	9.07	0.23

Mix 2

Species	% PLS	Ratio	PLS kg^{-1}	g plot^{-1}	g row^{-1}
Agropyron dasystachyum	95	0.10	334	7.02	0.18
Agropyron trachycaulum	89	0.10	284	8.81	0.22
Agrostis stolonifera	76	0.10	6114	0.48	0.01
Bouteloua gracilis	67	0.10	2246	1.48	0.04
Bromus carinatus	78	0.10	158	18.08	0.45
Festuca hallii	72	0.10	747	4.14	0.10
Festuca ovina	91	0.10	1359	1.80	0.05
Koeleria macrantha	76	0.10	4195	0.70	0.02
Poa palustris	88	0.10	5925	0.43	0.01
Stipa viridula	65	0.10	630	5.44	0.14

Mix 3

Species	% PLS	Ratio	PLS kg^{-1}	g plot^{-1}	g row^{-1}
Agropyron dasystachyum	95	0.12	334	8.19	0.20
Agropyron trachycaulum	89	0.12	284	10.28	0.26
Bouteloua gracilis	67	0.12	2246	1.73	0.04
Festuca hallii	72	0.12	747	4.83	0.12
Koeleria macrantha	76	0.12	4195	0.82	0.02
Stipa viridula	65	0.12	630	6.35	0.16
Achillea millefolium	76	0.03	7553	0.12	
Aster laevis	35	0.03	2370	0.81	
Gaillardia aristata	68	0.03	373	2.63	
Linum lewisii	71	0.03	692	1.36	
Monarda fistulosa	37	0.03	3743	0.48	
Petalostemon purpureum	78	0.03	636	1.35	
Ratibida columnifera	11	0.03	3355	1.81	
Solidago canadensis	10	0.03	9818	0.68	
Solidago missouriensis	20	0.03	3768	0.89	
Vicia americana	87	0.03	79	9.72	

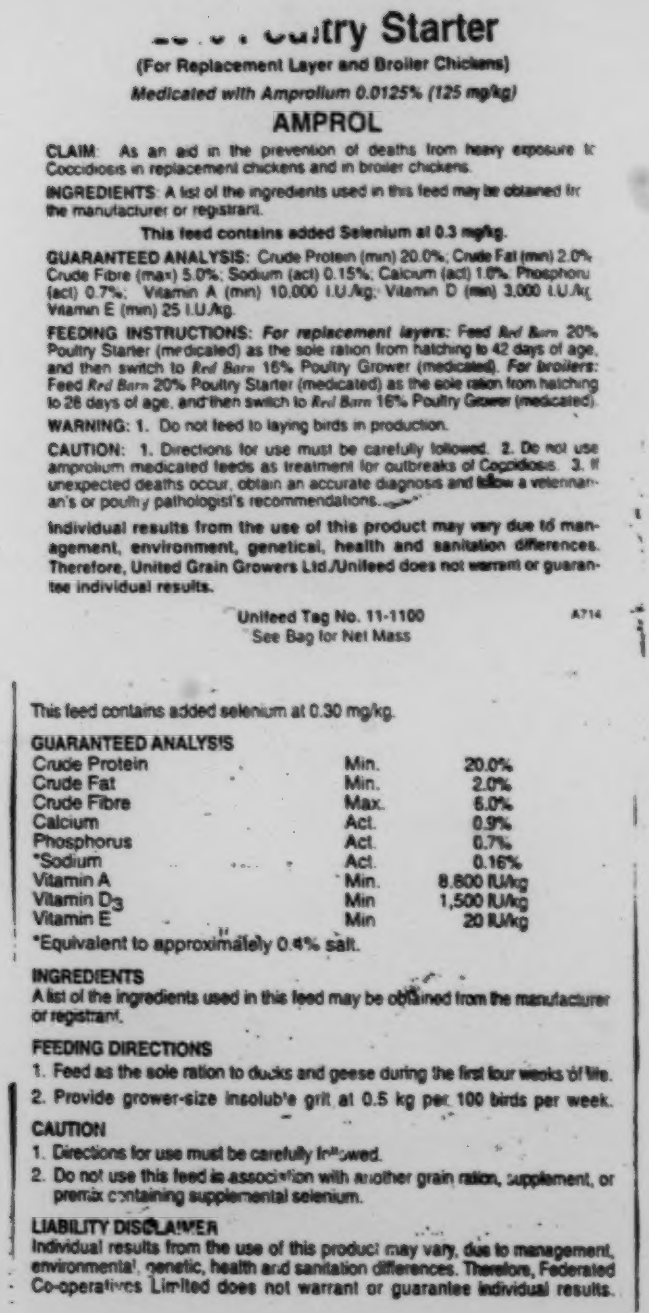
Table B.1. Seed mix calculations[1] for four mixes seeded at Ellerslie and Tawayik Lake and Oster Lake, Elk Island National Park (cont'd)

			Mix 4		
Species	% PLS	Ratio	PLS kg^{-1}	g plot^{-1}	g row^{-1}
Agropyron dasystachyum	95	0.07	334	4.91	0.12
Agropyron trachycaulum	89	0.07	284	6.17	0.15
Agrostis stolonifera	76	0.07	6114	0.34	0.01
Bouteloua gracilis	67	0.07	2246	1.04	0.03
Bromus carinatus	78	0.07	158	12.65	0.32
Festuca hallii	72	0.07	747	2.90	0.07
Festuca ovina	91	0.07	1359	1.26	0.03
Koeleria macrantha	76	0.07	4195	0.49	0.01
Poa palustris	88	0.07	5925	0.30	0.01
Stipa viridula	65	0.07	630	3.81	0.10
Achillea millefolium	76	0.03	7553	0.12	
Aster laevis	35	0.03	2370	0.81	
Linum lewisii	71	0.03	692	1.36	
Monarda fistulosa	37	0.03	3743	0.48	
Petalostemon purpureum	78	0.03	636	1.35	
Ratibida columnifera	11	0.03	3355	1.81	
Solidago canadensis	10	0.03	9818	0.68	
Solidago missouriensis	20	0.03	3768	0.89	
Vicia americana	87	0.03	79	9.72	

[1] For all mixes, PLS was 200 seeds m^{-2} and area was 111.38 m^{2}

Table B.2. Weed and other seeds found in bulk seed

Scientific name	Common name
Achillea millefolium L.	Common yarrow
Brassica sp.	Mustard
Bromus sp.	Bromegrass
Capsella bursa-pastoris (L.) Medic	Shepherd's purse
Carex sp.	Sedge
Crepis sp.	Hawksbeard
Festuca sp.	Rough fescue spp.
Helictotrichon hookeri (Scribn.) Henr.	Hooker's oat grass
Melilotus sp.	Sweet clover
Phleum pratense L.	Timothy
Plantago sp.	Plantain
Poa pratensis L.	Kentucky bluegrass
Potentilla sp.	Cinquefoil
Sonchus oleraceus L.	Annual sow-thistle
Trifolium hybridium L.	Alsike clover



[illegible] Poultry Starter

(For Replacement Layer and Broiler Chickens)

Medicated with Amprollum 0.0125% (125 mg/kg)

AMPROL

CLAIM: As an aid in the prevention of deaths from heavy exposure t Coccidiosis in replacement chickens and in broiler chickens.

INGREDIENTS: A list of the ingredients used in this feed may be obtained fr the manufacturer or registrant.

This feed contains added Selenium at 0.3 mg/kg.

GUARANTEED ANALYSIS: Crude Protein (min) 20.0%; Crude Fat (min) 2.0% Crude Fibre (max) 5.0%; Sodium (act) 0.15%; Calcium (act) 1.0%; Phosphoru (act) 0.7%; Vitamin A (min) 10,000 I.U./kg; Vitamin D (min) 3,000 I.U./k Vitamin E (min) 25 I.U./kg.

FEEDING INSTRUCTIONS: ***For replacement layers:*** Feed *Red Barn* 20% Poultry Starter (medicated) as the sole ration from hatching to 42 days of age, and then switch to *Red Barn* 16% Poultry Grower (medicated). ***For broilers:*** Feed *Red Barn* 20% Poultry Starter (medicated) as the sole ration from hatching to 28 days of age, and then switch to *Red Barn* 16% Poultry Grower (medicated).

WARNING: 1. Do not feed to laying birds in production.

CAUTION: 1. Directions for use must be carefully followed. 2. Do not use amprolium medicated feeds as treatment for outbreaks of Coccidiosis. 3. If unexpected deaths occur, obtain an accurate diagnosis and follow a veterinarian's or poultry pathologist's recommendations.

Individual results from the use of this product may vary due to management, environment, genetical, health and sanitation differences. Therefore, United Grain Growers Ltd./Unifeed does not warrant or guarantee individual results.

Unifeed Tag No. 11-1100
See Bag for Net Mass

A714

This feed contains added selenium at 0.30 mg/kg.

GUARANTEED ANALYSIS

Crude Protein	Min.	20.0%
Crude Fat	Min.	2.0%
Crude Fibre	Max.	6.0%
Calcium	Act.	0.9%
Phosphorus	Act.	0.7%
*Sodium	Act.	0.16%
Vitamin A	Min.	8,600 IU/kg
Vitamin D_3	Min	1,500 IU/kg
Vitamin E	Min	20 IU/kg

*Equivalent to approximately 0.4% salt.

INGREDIENTS
A list of the ingredients used in this feed may be obtained from the manufacturer or registrant.

FEEDING DIRECTIONS

1. Feed as the sole ration to ducks and geese during the first four weeks of life.
2. Provide grower-size insoluble grit at 0.5 kg per 100 birds per week.

CAUTION

1. Directions for use must be carefully followed.
2. Do not use this feed in association with another grain ration, supplement, or premix containing supplemental selenium.

LIABILITY DISCLAIMER
Individual results from the use of this product may vary, due to management, environmental, genetic, health and sanitation differences. Therefore, Federated Co-operatives Limited does not warrant or guarantee individual results.

Figure B.1. Package label of duck and geese starter used as a carrier for seeding

APPENDIX C. DESCRIPTION OF STATISTICAL PROCEDURES USED TO ANALYZE DATA

C.1. Statistical Analyses

The SAS Version for Windows V6.12 was the statistical software used. The General Linear Model (GLM) was used to test for interaction effects and the significance of main effects. Orthogonal contrasts were used to contrast where an effect was significant. A p-value of less than 0.05 is sufficient to reject the null hypothesis in each of the following analyses (Mapfumo 1999).

Within each quadrat, density, percent biovolume, canopy and ground cover data were collected. The density and percent biovolume data were later multiplied together for each quadrat, to form density-biovolume data. Data were sorted by site (Tawayik Lake, Oster Lake, and Ellerslie), and were analyzed separately according to species grouping (seeded species, seeded grasses, seeded forbs, non-seeded species, non-seeded grasses, non-seeded forbs and total species).

Post-hoc comparisons between years were conducted using the t-test for paired observations. However, use of the t-test for paired observations was limited to comparisons where the sample size was the same for both years.

C.2. Split-Plot and Split-Split Plot Models

Split-Plot Model

$Y_{ijk} = \mu + \rho_k + \alpha_i + \varepsilon_{ik} + \beta_j + (\alpha\beta)_{ij} + \phi_{ijk}$

$i = 1 \ldots \alpha; \quad j = 1 \ldots \beta; \quad k = 1 \ldots \rho$

Where: Y_{ijkl} = the plant, canopy or ground cover parameter;

μ= the grand mean;

ρ_k = the effect of the kth block;

α_i = the effect of the ith seasonmow;

ε_{ik} = the main plot error;

β_j = the effect of the jth mix;

$(\alpha\beta)_{ij}$ = the effect of interaction between the ith seasonmow and the jth mix;

ϕ_{ijk} = the residual error associated with subplot.

Assuming $\varepsilon_{ik} \sim^{iid} N(0, \sigma^2_w)$, $\Phi_{ijk} \sim^{iid} N(0, \sigma^2_s)$

Split-Plot

Source of Variation	Degrees of Freedom (df)	Ellerslie df	Oster Lake df	Tawayik Lake df
Block	ρ-1	3	1	1
Seasonmow	α-1	2	2	2
Error (a)	$(\rho-1)(\alpha-1)$	6	2	2
Mix	β-1	3	3	3
Mix*Seasonmow	$(\alpha-1)(\beta-1)$	6	6	6
Error (b)	$\alpha(\rho-1)(\beta-1)$	27	9	9
Total	$\alpha\rho\beta$-1	47	23	23

Split-Split Plot Model

$$Y_{ijkl} = \mu + \rho_k + \alpha_i + \varepsilon_{ik} + \beta_j + (\alpha\beta)_{ij} + \phi_{ijk} + \delta_l + (\delta\beta)_{jl} + (\alpha\delta)_{il} + (\alpha\beta\delta)_{ijl} + \rho_{ijkl}$$

$i = 1\ldots\alpha;\quad j = 1\ldots\beta;\quad k = 1\ldots\rho;\quad l = 1\ldots\delta$

Where: Y_{ijkl} = the plant, canopy or ground cover parameter;

μ = the grand mean;

ρ_k = the effect of the kth block;

α_i = the effect of the ith season;

ε_{ik} = the whole plot error;

β_j = the effect of the jth mow;

$(\alpha\beta)_{ij}$ = the effect of interaction between the ith season and the jth mow;

ϕ_{ijk} = the subplot error;

δ_l = the effect of the lth mix;

$(\delta\beta)_{jl}$ = the effect of interaction between the jth mow and the lth mix;

$(\alpha\delta)_{il}$ = the effect of interaction between the ith season and the lth mix;

$(\alpha\beta\delta)_{ijl}$ = the effect of interaction between the ith season, jth mow and the lth mix;

ρ_{ijkl} = the residual error associated with sub-sub plot.

Assuming $\varepsilon_{ik} \sim^{iid} N(0, \sigma^2_w)$, $\Phi_{ijk} \sim^{iid} N(0, \sigma^2_s)$

Split-Split Plot

Source of Variation	Degrees of Freedom (df)	Ellerslie df	Oster Lake df	Tawayik Lake df
Block	ρ-1	3	1	1
Season	α-1	1	1	1
Error (a)	$(\alpha-1)(\rho-1)$	3	1	1
Mow	β-1	1	1	1
Mow*Season	$(\beta-1)(\alpha-1)$	1	1	1
Error (b)	$(\rho-1)\alpha(\beta-1)$	6	2	2
Mix	δ-1	3	3	3
Mix*Season	$(\delta-1)(\alpha-1)$	3	3	3
Mix*Mow	$(\delta-1)(\beta-1)$	3	3	3
Mix*Season*Mow	$(\delta-1)(\alpha-1)(\beta-1)$	3	3	3
Error (c)	$\alpha\beta(\rho-1)(\delta-1)$	36	12	12
Total	$\alpha\beta\delta\rho-1$	63	31	31

C.3. GLM Analysis and Orthogonal Contrasts of the Interaction of Main Effects

Interaction of the main effects was determined using the GLM. For the 1998 data, if the interaction of the two main effects (season-mow and mix treatments) was statistically significant, an orthogonal contrast was conducted to determine which of the three season-mow treatments were significantly interacting with which of the four mix treatments. For the 1999 data, if the three-way interaction of the main effects (season and mow and mix treatments) or any two-way interaction combination of the main effects was statistically significant, histograms were used to study general trends. Theoretically, a significant interaction would prevent the main effects from being examined independently. However, orthogonal contrasts were conducted on main effects influenced by a significant interaction.

C.4. GLM Analysis and Orthogonal Contrasts of the Season

The 1998 season-mow and 1999 season treatments were analyzed using the GLM. If the season-mow/season was statistically significant, an orthogonal contrast was conducted to determine if fall and spring seasons of seeding were different. For 1998 data, the contrast was done on fall unmow and spring unmow treatments to determine if seasons were different. For the 1999 data, the contrast was done on the pooled data of mowed and unmowed treatments of both seasons of seeding, to determine if the seasons were different.

C.5. GLM Analysis and Orthogonal Contrasts of the Mowing

The 1998 season-mow and 1999 mow treatments were analyzed using the GLM. If the season-mow/mow was statistically significant, an orthogonal contrast was conducted to determine if mow and unmow treatments were different. For 1998 data, the contrast was done on fall mow and fall unmow treatments to determine if mow and unmow were different. For the 1999 data, the contrast was done on the pooled data of fall and spring seeded mow and unmow treatments, to determine if mow and unmow were different.

C.6. Wilcoxon Signed Rank Test of Species Richness in the Seed Mix and the Plant Community

Species richness was analyzed using the count of the total number of species present per m^2. A Wilcoxon signed rank test was used to determine if there was a difference between what was seeded and what was present. The number of grass and the number of forb species seeded versus present was compared at each site, and within each site between the season-mow (1998), season (1999), mow (1999) and mix treatments.

C.7. GLM Analysis and Orthogonal Contrasts of the Mix for Common Grasses

Mix data from the six grass species common to all four mixes was analyzed using the GLM. If the mix treatment was statistically significant, an orthogonal contrast of the four mixes was conducted to determine whether or not there were differences in the common grasses present in seed mixes of differing levels of species richness.

C.8. GLM Analysis and Orthogonal Contrasts of the Mix for Non-Seeded Species, Non-Seeded Grasses and Non-Seeded Forbs

Mix data for non-seeded species categories was analyzed using the GLM. If the mix treatment was statistically significant, an orthogonal contrast of the four mixes was conducted to determine which mix(es) differed for non-seeded species presence.

C.9. GLM Analysis and Orthogonal Contrasts of Canopy and Ground Cover

To determine if (and which) season, mowing, and/or mix treatment is significant to canopy and ground cover measurements, a GLM was used. If the season-mow/season was statistically significant, an orthogonal contrast was conducted to determine if canopy or ground cover of fall and spring seasons of seeding were different. For the 1998 data, the contrast was done on fall unmow and spring unmow treatments. For the 1999 data, the contrast was done on pooled data of mowed and unmowed treatments of both seasons of seeding.

If the season-mow/mow was statistically significant, an orthogonal contrast was also conducted to determine if canopy and ground cover of mow and unmow treatments were different. For the 1998 data, the contrast was done on fall mow and fall unmow treatments. For the 1999 data, the contrast was done on the pooled data of fall and spring seeded mow and unmow treatments.

If the mix treatment was statistically significant, an orthogonal contrast was conducted to determine which of the four mixes were different for canopy and ground cover.

C.10. Literature Cited

Mapfumo, Dr. E. 1999. Personal communication. Statistical advisor. Department of Renewable Resources, University of Alberta.

APPENDIX D. STATISTICAL SUMMARY INFORMATION

Table D.1. **P values and significance of season-mow*mix interactions for July 1998 data from Ellerslie and Tawayik Lake and Oster Lake, Elk Island National Park**

Parameter	Density (plants m^{-2})			% Biovolume			Density-Biovolume		
	Tawayik Lake	Oster Lake	Ellerslie	Tawayik Lake	Oster Lake	Ellerslie	Tawayik Lake	Oster Lake	Ellerslie
Total seeded	0.0003*	0.1333	0.0050*	0.0312*	0.5681	0.1300	0.3829	0.6514	0.1837
Seeded grasses	0.0680	0.8868	0.0028*	0.0438*	0.8531	0.1218	0.4371	0.9297	0.1880
Seeded forbs	0.0197*	0.1607	0.1917	0.2378	0.2830	0.5031	0.2062	0.4149	0.4381
Total non-seeded	0.0697	0.0001*	0.0291*	0.0312*	0.5681	0.1435	0.0969	0.0001*	0.0502
Non-seeded grasses	0.0717	0.0568	0.6520	0.3989	0.5123	0.6146	0.4206	0.6574	0.4465
Non-seeded forbs	0.0947	0.0001*	0.0352*	0.0385*	0.5082	0.0606	0.0873	0.0001*	0.0217*
Total all	0.1117	0.0001*	0.0349*						

* indicates value significant at α=0.05

Table D.2. P values and significance of season-mow*mix interaction contrasts for July 1998 data from Ellerslie and Tawayik Lake and Oster Lake, Elk Island National Park

	Density (plants m^{-2})			% Biovolume			Density-Biovolume		
Parameter	Tawayik Lake	Oster Lake	Ellerslie	Tawayik Lake	Oster Lake	Ellerslie	Tawayik Lake	Oster Lake	Ellerslie
Fall unmow vs. spring unmow * mix 1,2 vs. 3,4									
Total seeded	0.0468*		0.3251	0.2586					
Seeded grasses			0.0862	0.1636					
Seeded forbs	0.4080								
Total non-seeded		0.0530	0.3355	0.2586				0.0147*	
Non-seeded grasses									
Non-seeded forbs		0.0277*	0.3817	0.1179				0.0132*	0.0727
Total all		0.3473	0.5713						
Fall mow vs. fall unmow * mix 1,2 vs. 3,4									
Total seeded	0.9199		0.0279*	0.8859					
Seeded grasses			0.0478*	0.9303					
Seeded forbs	0.7742								
Total non-seeded		0.1587	0.7641	0.8859				0.1276	
Non-seeded grasses									
Non-seeded forbs		0.1241	0.7222	0.9369				0.1281	0.2141
Total all		0.0421*	0.6176						

Table D.2. P values and significance of season-mow*mix interaction contrasts for July 1998 data from Ellerslie and Tawayik Lake and Oster Lake, Elk Island National Park (cont'd)

	Density (plants m^{-2})			% Biovolume			Density-Biovolume		
Parameter	Tawayik Lake	Oster Lake	Ellerslie	Tawayik Lake	Oster Lake	Ellerslie	Tawayik Lake	Oster Lake	Ellerslie
Fall unmow vs. spring unmow * mix 1 vs. 2									
Total seeded	0.0002*		0.5390	0.4307					
Seeded grasses			0.4994	0.3336					
Seeded forbs	0.0007*								
Total non-seeded		0.4640	0.0583	0.4307				0.1803	
Non-seeded grasses									
Non-seeded forbs		0.4229	0.0630	0.9427				0.1805	0.6331
Total all		0.3951	0.1132						
Fall mow vs. fall unmow * mix 1 vs. 2									
Total seeded	0.6699		0.1783	0.9568					
Seeded grasses			0.1390	0.9671					
Seeded forbs	0.3619								
Total non-seeded		0.3769	0.1943	0.9568				0.9871	
Non-seeded grasses									
Non-seeded forbs		0.4511	0.0245*	0.9405				0.9871	0.2309
Total all		0.5920	0.0871						

Table D.2. P values and significance of season-mow*mix interaction contrasts for July 1998 data from Ellerslie and Tawayik Lake and Oster Lake, Elk Island National Park (cont'd)

	Density (plants m^{-2})			% Biovolume			Density-Biovolume		
Parameter	Tawayik Lake	Oster Lake	Ellerslie	Tawayik Lake	Oster Lake	Ellerslie	Tawayik Lake	Oster Lake	Ellerslie
Fall unmow vs. spring unmow * mix 3 vs. 4									
Total seeded	0.8696		0.0938	0.0099					
Seeded grasses			0.1921	0.0212*					
Seeded forbs	0.9533								
Total non-seeded		0.0001*	0.9878	0.0099*				0.0060*	
Non-seeded grasses									
Non-seeded forbs		0.0001*	0.8187	0.0165*				0.0071*	0.8432
Total all		0.0004*	0.5604						
Fall mow vs. fall unmow * mix 3 vs. 4									
Total seeded	0.3943		0.0403*	0.8604					
Seeded grasses			0.2424	0.8690					
Seeded forbs	0.6121								
Total non-seeded		0.1561	0.9366	0.8604				0.0688	
Non-seeded grasses									
Non-seeded forbs		0.1544	0.7308	0.8324				0.0692	0.6552
Total all		0.5555	0.5121						

Table D.2. P values and significance of season-mow*mix interaction contrasts for July 1998 data from Ellerslie and Tawayik Lake and Oster Lake, Elk Island National Park (cont'd)

	Density (plants m^{-2})			% Biovolume			Density-Biovolume		
Parameter	Tawayik Lake	Oster Lake	Ellerslie	Tawayik Lake	Oster Lake	Ellerslie	Tawayik Lake	Oster Lake	Ellerslie
Fall unmow vs. spring unmow * mix 1 vs. 3									
Total seeded	0.5659		0.6523	0.9129					
Seeded grasses			0.8218	0.7569					
Seeded forbs	0.2668								
Total non-seeded		0.0001*	0.7828	0.9129				0.0002*	
Non-seeded grasses									
Non-seeded forbs		0.0001*	0.6688	0.8914				0.0002*	0.2578
Total all		0.0041*	0.9188						
Fall mow vs. fall unmow * mix 1 vs. 3									
Total seeded	0.8870		0.0012*	0.9676					
Seeded grasses			0.0067*	0.9671					
Seeded forbs	0.6850								
Total non-seeded		0.4653	0.6907	0.9676				0.8740	
Non-seeded grasses									
Non-seeded forbs		0.4511	0.8323	0.9901				0.8740	0.6149
Total all		0.0458*	0.1247						

Table D.2. P values and significance of season-mow*mix interaction contrasts for July 1998 data from Ellerslie and Tawayik Lake and Oster Lake, Elk Island National Park (cont'd)

	Density (plants m^{-2})			% Biovolume			Density-Biovolume		
Parameter	Tawayik Lake	Oster Lake	Ellerslie	Tawayik Lake	Oster Lake	Ellerslie	Tawayik Lake	Oster Lake	Ellerslie
Fall unmow vs. spring unmow * mix 2 vs. 4									
Total seeded	0.0008*		0.0660	0.0888					
Seeded grasses			0.0279*	0.0971					
Seeded forbs	0.0236*								
Total non-seeded		0.1382	0.1020	0.0888				0.7495	
Non-seeded grasses									
Non-seeded forbs		0.2087	0.0965	0.0195*				0.7915	0.1585
Total all		0.1159	0.3670						
Fall mow vs. fall unmow * mix 2 vs. 4									
Total seeded	0.7762		0.8872	0.8710					
Seeded grasses			0.9378	0.8690					
Seeded forbs	1.0000								
Total non-seeded		0.2056	0.4111	0.8710				0.0465*	
Non-seeded grasses									
Non-seeded forbs		0.1544	0.4750	0.9009				0.0468*	0.2097
Total all		0.3769	0.4055						

* indicates value significant at α=0.05

Table D.3. P values and significance of season-mow for July 1998 data from Ellerslie and Tawayik Lake and Oster Lake, Elk Island National Park

	Density (plants m^{-2})			% Biovolume			Density-Biovolume		
Parameter	Tawayik Lake	Oster Lake	Ellerslie	Tawayik Lake	Oster Lake	Ellerslie	Tawayik Lake	Oster Lake	Ellerslie
Total seeded	0.0953**	0.6345	0.0290***	0.0176***	0.0142*	0.0001*	0.0107*	0.0243*	0.0001*
Seeded grasses	0.0788	0.2913	0.0036***	0.0089***	0.0052*	0.0001*	0.0069*	0.0095*	0.0002*
Seeded forbs	0.1481**	0.7764	0.7543	0.3092	0.1344	0.8942	0.1883	0.1269	0.8413
Total non-seeded	0.1613	0.1247**	0.0668**	0.0176***	0.0142*	0.0001*	0.0206*	0.2711**	0.0128*
Non-seeded grasses	0.3112	0.7500	0.3662	0.0305*	0.6448	0.1474	0.1056	0.4538	0.2708
Non-seeded forbs	0.1489	0.1524**	0.0367***	0.0191***	0.0043*	0.0001*	0.0191*	0.2715**	0.0097***
Total all	0.1612	0.4562**	0.2252**						

* indicates value significant at $\alpha=0.05$

** indicates value significant at a=0.05, affected by season-mow*mix interaction

*** indicates value affected by season-mow*mix interaction

Table D.4. P values and significance of season-mow contrasts for July 1998 data from Ellerslie and Tawayik Lake and Oster Lake, Elk Island National Park

	Density (plants m^{-2})			% Biovolume			Density-Biovolume		
Parameter	Tawayik Lake	Oster Lake	Ellerslie	Tawayik Lake	Oster Lake	Ellerslie	Tawayik Lake	Oster Lake	Ellerslie
Fall unmow vs. spring unmow									
Total seeded			0.0002**	0.0001**	0.0001*	0.0001*	0.0001*	0.0001*	0.0001*
Seeded grasses			0.0007**	0.0001**	0.0001*	0.0001*	0.0001*	0.0006*	0.0001*
Seeded forbs									
Total non-seeded				0.0001**	0.0001*	0.0001*	0.0047*		0.0765
Non-seeded grasses				0.0600					
Non-seeded forbs			0.0024**	0.0001**	0.0001*	0.0001*	0.0041*		0.0588***
Total all									
Fall mow vs. fall unmow									
Total seeded			0.0573***	0.6258***	0.5310	0.3613	0.8062	0.6867	0.6241
Seeded grasses			0.0987***	0.6760***	0.5028	0.4708	0.8393	0.6455	0.6574
Seeded forbs									
Total non-seeded				0.6258***	0.5310	0.3596	0.1114		0.3529
Non-seeded grasses				0.9692					
Non-seeded forbs			0.3126***	0.6663***	0.6077	0.6004	0.1124		0.2730***
Total all									

* indicates value significant at α=0.05

** indicates value significant at a=0.05, affected by season-mow*mix interaction

*** indicates value affected by season-mow*mix interaction

Table D.5. **P values and significance of mix for July 1998 data from Ellerslie and Tawayik Lake and Oster Lake, Elk Island National Park**

	Density (plants m^{-2})			% Biovolume			Density-Biovolume		
Parameter	Tawayik Lake	Oster Lake	Ellerslie	Tawayik Lake	Oster Lake	Ellerslie	Tawayik Lake	Oster Lake	Ellerslie
Total seeded	0.2829***	0.0038*	0.0022**	0.1933***	0.4718	0.0280*	0.5173	0.4671	0.0627
Seeded grasses	0.7413	0.5525	0.0103**	0.2297***	0.8888	0.0674	0.5803	0.7709	0.0567
Seeded forbs	0.4077***	0.0493*	0.0001*	0.3623	0.0699	0.0019*	0.3250	0.2753	0.0005*
Total non-seeded	0.2852	0.1144***	0.0480**	0.1933***	0.4718	0.0159*	0.0395*	0.1011***	0.0165*
Non-seeded grasses	0.6886	0.0207*	0.4435	0.4756	0.4953	0.2180	0.4579	0.6065	0.5165
Non-seeded forbs	0.3000	0.1320***	0.0306**	0.1991***	0.6660	0.0530	0.0461*	0.1011***	0.0220**
Total all	0.1860	0.0109**	0.1321***						

* indicates value significant at α=0.05

** indicates value significant at α=0.05, affected by season-mow*mix interaction

*** indicates value affected by season-mow*mix interaction

Table D.6. P values and significance of mix contrasts for July 1998 data from Ellerslie and Tawayik Lake and Oster Lake, Elk Island National Park

Parameter	Density (plants m^{-2})			% Biovolume			Density-Biovolume		
	Tawayik Lake	Oster Lake	Ellerslie	Tawayik Lake	Oster Lake	Ellerslie	Tawayik Lake	Oster Lake	Ellerslie
Mix 1,2 vs. 3,4									
Total seeded		0.0103*	0.0110**			0.1619			
Seeded grasses			0.5539***						
Seeded forbs		0.0159*	0.0001*			0.0001*			0.0001*
Total non-seeded			0.0534***			0.1604	0.0834		0.0085*
Non-seeded grasses		0.0935							
Non-seeded forbs		0.0033**	0.0363**				0.0902		0.0085**
Total all									
Mix 1 vs. 2									
Total seeded		0.7969	0.0041**			0.0304*			
Seeded grasses			0.0016**						
Seeded forbs		1.0000	1.0000			1.0000			1.0000
Total non-seeded			0.9056***			0.0201*	0.0239*		0.0663
Non-seeded grasses		0.6160							
Non-seeded forbs		0.1417***	0.9811***				0.0272*		0.0142**
Total all									

Table D.6. P values and significance of mix contrasts for July 1998 data from Ellerslie and Tawayik Lake and Oster Lake, Elk Island National Park (cont'd)

	Density (plants m^{-2})			% Biovolume			Density-Biovolume		
Parameter	Tawayik Lake	Oster Lake	Ellerslie	Tawayik Lake	Oster Lake	Ellerslie	Tawayik Lake	Oster Lake	Ellerslie
Mix 3 vs. 4									
Total seeded		0.1491	0.9242***			0.1128			
Seeded grasses			0.3121***						
Seeded forbs		0.1509	0.0357*			0.6792			0.4145
Total non-seeded			0.0408**			0.0811	0.5812		0.9314
Non-seeded grasses		0.0092*							
Non-seeded forbs			0.0328**				0.5818		0.7691***
Total all		0.5099***							
Mix 1 vs. 3									
Total seeded		0.0162*	0.6800***			0.4848			
Seeded grasses			0.1343***						
Seeded forbs		0.0156*	0.0001*			0.0034*			0.0009*
Total non-seeded			0.7759***			0.4833	0.7133		0.3644
Non-seeded grasses		0.9002							
Non-seeded forbs			0.6701***				0.7148		0.3625***
Total all		0.0902***							

Table D.6. P values and significance of mix contrasts for July 1998 data from Ellerslie and Tawayik Lake and Oster Lake, Elk Island National Park (cont'd)

	Density (plants m^{-2})			% Biovolume			Density-Biovolume		
Parameter	Tawayik Lake	Oster Lake	Ellerslie	Tawayik Lake	Oster Lake	Ellerslie	Tawayik Lake	Oster Lake	Ellerslie
Mix 2 vs. 4									
Total seeded		0.2167	0.0015**			0.2002			
Seeded grasses			0.5076***						
Seeded forbs		0.3178	0.0001*			0.0016*			0.0113*
Total non-seeded			0.0145**			0.1986	0.0377*		0.0049*
Non-seeded grasses		0.0252*							
Non-seeded forbs			0.0114**				0.0426*		0.0049**
Total all		0.0127**							

* indicates value significant at α=0.05
** indicates value significant at α=0.05, affected by season-mow*mix interaction
*** indicates value affected by season-mow*mix interaction

Table D.7 **P values and significance of season-mow*mix interactions for July 1998 common grasses data from Ellerslie and Tawayik Lake and Oster Lake, Elk Island National Park**

Species	Density (plants m^{-2})			% Biovolume			Density-Biovolume		
	Tawayik Lake	Oster Lake	Ellerslie	Tawayik Lake	Oster Lake	Ellerslie	Tawayik Lake	Oster Lake	Ellerslie
Agropyron dasystachyum	0.9810	0.2353	0.0086*	0.4628	0.8844	0.8864	0.6171	0.9039	0.9539
Agropyron trachycaulum	0.6817	0.8344	0.0088*	0.0162*	0.7821	0.0865	0.3119	0.8987	0.1696
Bouteloua gracilis	0.8200	0.8200	0.8168	0.8200	0.8200	0.8168	0.8200	0.8200	0.8168
Festuca hallii	0.0077*	0.8076	0.6137	0.0134*	0.3988	0.5926	0.0123*	0.3998	0.7497
Koeleria macrantha	0.3798		0.7802	0.8261		0.4501	0.7845		0.4503
Stipa viridula	0.8693	0.7835	0.4900	0.3907	0.2694	0.4455	0.7961	0.2331	0.4105

Blank indicates species not present at that site

* indicates value significant at α=0.05

Table D.8. P values and significance of season-mow*mix interaction contrasts for July 1998 common grasses data from Ellerslie and Tawayik Lake and Oster Lake, Elk Island National Park

	Density (plants m^{-2})			% Biovolume			Density-Biovolume		
Parameter	Tawayik Lake	Oster Lake	Ellerslie	Tawayik Lake	Oster Lake	Ellerslie	Tawayik Lake	Oster Lake	Ellerslie
Fall unmow vs. spring unmow * mix 1,2 vs. 3,4									
Agropyron dasystachyum			0.0832						
Agropyron trachycaulum			0.4040	0.4980					
Bouteloua gracilis									
Festuca hallii	0.0271*			0.0342*			0.0360*		
Koeleria macrantha									
Stipa viridula									
Fall mow vs. fall unmow * mix 1,2 vs. 3,4									
Agropyron dasystachyum			0.5728						
Agropyron trachycaulum			0.0100*	0.8763					
Bouteloua gracilis									
Festuca hallii	0.6680			0.6418			0.7394		
Koeleria macrantha									
Stipa viridula									
Fall unmow vs. spring unmow * mix 1 vs. 2									
Agropyron dasystachyum			0.0467*						
Agropyron trachycaulum			0.3255	0.0060*					
Bouteloua gracilis									
Festuca hallii	0.0019*			0.0030*			0.0032*		
Koeleria macrantha									
Stipa viridula									

Table D.8. P values and significance of season-mow*mix interaction contrasts for July 1998 common grasses data from Ellerslie and Tawayik Lake and Oster Lake, Elk Island National Park (cont'd)

	Density (plants m^{-2})			% Biovolume			Density-Biovolume		
Parameter	Tawayik Lake	Oster Lake	Ellerslie	Tawayik Lake	Oster Lake	Ellerslie	Tawayik Lake	Oster Lake	Ellerslie
Fall mow vs. fall unmow * mix 1 vs. 2									
Agropyron dasystachyum			0.4252						
Agropyron trachycaulum			0.3944	0.9203					
Bouteloua gracilis									
Festuca hallii	0.5443			0.5617			0.6381		
Koeleria macrantha									
Stipa viridula									
Fall unmow vs. spring unmow * mix 3 vs. 4									
Agropyron dasystachyum			0.2830						
Agropyron trachycaulum			0.2795	0.0158*					
Bouteloua gracilis									
Festuca hallii	1.0000			1.0000			1.0000		
Koeleria macrantha									
Stipa viridula									
Fall mow vs. fall unmow * mix 3 vs. 4									
Agropyron dasystachyum			0.5949						
Agropyron trachycaulum			0.2684	0.7488					
Bouteloua gracilis									
Festuca hallii	1.0000			1.0000			1.0000		
Koeleria macrantha									
Stipa viridula									

Table D.8. P values and significance of season-mow*mix interaction contrasts for July 1998 common grasses data from Ellerslie and Tawayik Lake and Oster Lake, Elk Island National Park (cont'd)

	Density (plants m^{-2})			% Biovolume			Density-Biovolume		
Parameter	Tawayik Lake	Oster Lake	Ellerslie	Tawayik Lake	Oster Lake	Ellerslie	Tawayik Lake	Oster Lake	Ellerslie
Fall unmow vs. spring unmow * mix 1 vs. 3									
Agropyron dasystachyum			0.0920						
Agropyron trachycaulum			0.6579	0.8533					
Bouteloua gracilis									
Festuca hallii	1.0000			1.0000			1.0000		
Koeleria macrantha									
Stipa viridula									
Fall mow vs. fall unmow * mix 1 vs. 3									
Agropyron dasystachyum			0.2879						
Agropyron trachycaulum			0.0052*	0.9203					
Bouteloua gracilis									
Festuca hallii	1.0000			1.0000			1.0000		
Koeleria macrantha									
Stipa viridula									
Fall unmow vs. spring unmow * mix 2 vs. 4									
Agropyron dasystachyum			0.4429						
Agropyron trachycaulum			0.1052	0.4392					
Bouteloua gracilis									
Festuca hallii	0.0019*			0.0030*			0.0032*		
Koeleria macrantha									
Stipa viridula									

Table D.8. P values and significance of season-mow*mix interaction contrasts for July 1998 common grasses data from Ellerslie and Tawayik Lake and Oster Lake, Elk Island National Park (cont'd)

	Density (plants m^{-2})			% Biovolume			Density-Biovolume		
Parameter	Tawayik Lake	Oster Lake	Ellerslie	Tawayik Lake	Oster Lake	Ellerslie	Tawayik Lake	Oster Lake	Ellerslie
Fall mow vs. fall unmow * mix 2 vs. 4									
Agropyron dasystachyum			0.7903						
Agropyron trachycaulum			0.3944	0.7488					
Bouteloua gracilis									
Festuca hallii	0.5443			0.5617			0.6381		
Koeleria macrantha									
Stipa viridula									

* indicates value significant at α=0.05

Table D.9. P values and significance of season-mow for July 1998 common grasses data from Ellerslie and Tawayik Lake and Oster Lake, Elk Island National Park

	Density (plants m^{-2})			% Biovolume			Density-Biovolume		
Species	Tawayik Lake	Oster Lake	Ellerslie	Tawayik Lake	Oster Lake	Ellerslie	Tawayik Lake	Oster Lake	Ellerslie
Agropyron dasystachyum	0.1401	0.3400	0.3349***	0.1106	0.1518	0.0058*	0.3386	0.1967	0.0064*
Agropyron trachycaulum	0.1226	0.3400	0.0052**	0.0001**	0.0002*	0.0001*	0.0415*	0.0067*	0.0004*
Bouteloua gracilis	0.5000	0.5000	0.4219	0.5000	0.5000	0.4219	0.5000	0.5000	0.4219
Festuca hallii	0.0833***	0.7500	0.0356*	0.0530***	0.6266	0.0530	0.0192**	0.6266	0.0627
Koeleria macrantha	0.2647		0.4219	0.0001*		0.5228	0.0322*		0.4659
Stipa viridula	0.3820	0.3667	0.8074	0.2883	0.2883	0.6621	0.4628	0.2684	0.9447

Blank indicates species not present at that site

* indicates value significant at α=0.05

** indicates value significant at a=0.05, affected by season-mow*mix interaction

*** indicates value affected by season-mow*mix interaction

Table D.10. P values and significance of season-mow contrasts for July 1998 common grasses data from Ellerslie and Tawayik Lake and Oster Lake, Elk Island National Park

	Density (plants m^{-2})			% Biovolume			Density-Biovolume		
Species	Tawayik Lake	Oster Lake	Ellerslie	Tawayik Lake	Oster Lake	Ellerslie	Tawayik Lake	Oster Lake	Ellerslie
Fall unmow vs. spring unmow									
Agropyron dasystachyum						0.0080*			0.0648
Agropyron trachycaulum			0.0185**	0.0001**	0.0001*	0.0001*	0.0001*	0.0010*	0.0001*
Bouteloua gracilis									
Festuca hallii			0.1711				0.0360**		
Koeleria macrantha				0.1702			0.1610		
Stipa viridula									
Fall mow vs. fall unmow									
Agropyron dasystachyum						0.7727			0.9454
Agropyron trachycaulum			0.3664***	0.6007***	0.5931	0.5942	0.7933	0.6832	0.6627
Bouteloua gracilis									
Festuca hallii			0.6923				0.7394***		
Koeleria macrantha		not present		1.0000	not present		1.0000	not present	
Stipa viridula									

* indicates value significant at α=0.05

** indicates value significant at a=0.05, affected by season-mow*mix interaction

*** indicates value affected by season-mow*mix interaction

Table D.11. P values and significance of mix for July 1998 common grasses data from Ellerslie and Tawayik Lake and Oster Lake, Elk Island National Park

Species	Density (plants m^{-2})			% Biovolume			Density-Biovolume		
	Tawayik Lake	Oster Lake	Ellerslie	Tawayik Lake	Oster Lake	Ellerslie	Tawayik Lake	Oster Lake	Ellerslie
Agropyron dasystachyum	0.8783	0.3188	0.2766***	0.4510	0.6814	0.7118	0.5944	0.6939	0.6844
Agropyron trachycaulum	0.8871	0.5066	0.0016**	0.1545***	0.8468	0.0238*	0.4553	0.7059	0.0512
Bouteloua gracilis	0.4628	0.7268	0.7597	0.7628	0.7628	0.7597	0.7628	0.7628	0.7597
Festuca hallii	0.0049**	0.1498	0.2488	0.0080**	0.1113	0.5849	0.0124**	0.1113	0.7022
Koeleria macrantha	0.4632		0.9905	0.7676		0.7057	0.7359		0.6611
Stipa viridula	0.1311	0.4289	0.3156	0.1436	0.4799	0.3776	0.5591	0.5402	0.3930

Blank indicates species not present at that site

* indicates value significant at α=0.05

** indicates value significant at α=0.05, affected by season-mow*mix interaction

*** indicates value affected by season-mow*mix interaction

Table D.12. P values and significance of mix contrasts for July 1998 common grasses data from Ellerslie and Tawayik Lake and Oster Lake, Elk Island National Park

	Density (plants m^{-2})			% Biovolume			Density-Biovolume		
Species	Tawayik Lake	Oster Lake	Ellerslie	Tawayik Lake	Oster Lake	Ellerslie	Tawayik Lake	Oster Lake	Ellerslie
Mix 1,2 vs. 3,4									
Agropyron dasystachyum									
Agropyron trachycaulum			0.5534***			0.8708			
Bouteloua gracilis									
Festuca hallii	0.0362**			0.0449**					
Koeleria macrantha									
Stipa viridula									
Mix 1 vs. 2									
Agropyron dasystachyum									
Agropyron trachycaulum			0.0002**			0.0077*			
Bouteloua gracilis									
Festuca hallii	0.0033**			0.0048**					
Koeleria macrantha									
Stipa viridula									
Mix 3 vs. 4									
Agropyron dasystachyum									
Agropyron trachycaulum			0.2354***			0.1257			
Bouteloua gracilis									
Festuca hallii	1.0000***			1.0000***					
Koeleria macrantha									
Stipa viridula									

Table D.12. P values and significance of mix contrasts for July 1998 common grasses data from Ellerslie and Tawayik Lake and Oster Lake, Elk Island National Park

	Density (plants m^{-2})			% Biovolume			Density-Biovolume		
Species	Tawayik Lake	Oster Lake	Ellerslie	Tawayik Lake	Oster Lake	Ellerslie	Tawayik Lake	Oster Lake	Ellerslie
Mix 1 vs. 3									
Agropyron dasystachyum									
Agropyron trachycaulum			0.0871***			0.6446			
Bouteloua gracilis									
Festuca hallii	1.0000***			1.0000***					
Koeleria macrantha									
Stipa viridula									
Mix 2 vs. 4									
Agropyron dasystachyum									
Agropyron trachycaulum			0.3810***			0.4913			
Bouteloua gracilis									
Festuca hallii	0.0033**			0.0048**					
Koeleria macrantha									
Stipa viridula									

* indicates value significant at α=0.05

** indicates value significant at α=0.05, affected by season-mow*mix interaction

*** indicates value affected by season-mow*mix interaction

Table D.13. P values and significance of season-mow*mix interactions for July 1998 ground cover and canopy data from Ellerslie and Tawayik Lake and Oster Lake, Elk Island National Park

Parameter	Tawayik Lake	Oster Lake	Ellerslie
% Live vegetation	0.0167*	0.0085*	0.3361
% Bare ground	0.0167*	0.0070*	0.2082
% Live canopy	0.0002*	0.0015*	0.3112
% Dead canopy	0.0001*	0.0553	0.0042*

* indicates value significant at $\alpha=0.05$

Table D.14. **P values and significance of season-mow*mix interaction contrasts for July 1998 ground cover and canopy data from Ellerslie and Tawayik Lake and Oster Lake, Elk Island National Park**

	Site		
Parameter	Tawayik Lake	Oster Lake	Ellerslie
Fall unmow vs. spring unmow * mix 1,2 vs. 3,4			
% Live vegetation	0.9812	0.3117	
% Bare ground	0.9812	0.2907	
% Live canopy	0.0001*	0.0226*	
% Dead canopy	0.0004*		0.0472*
Fall mow vs. fall unmow * mix 1,2 vs. 3,4			
% Live vegetation	0.4223	0.2484	
% Bare ground	0.4223	0.2487	
% Live canopy	0.4557	0.5520	
% Dead canopy	0.0444*		0.0051*
Fall unmow vs. spring unmow * mix 1 vs. 2			
% Live vegetation	0.0469*	0.4740	
% Bare ground	0.0469*	0.4743	
% Live canopy	1.0000	0.0327*	
% Dead canopy	0.8749		0.0854
Fall mow vs. fall unmow * mix 1 vs. 2			
% Live vegetation	0.7290	0.0253*	
% Bare ground	0.7290	0.0254*	
% Live canopy	0.9049	0.3861	
% Dead canopy	0.9689		0.3826
Fall unmow vs. spring unmow * mix 3 vs. 4			
% Live vegetation	0.0018*	0.0238*	
% Bare ground	0.0018*	0.0202*	
% Live canopy	0.0103*	0.6543	
% Dead canopy	0.0001*		0.0164*
Fall mow vs. fall unmow * mix 3 vs. 4			
% Live vegetation	0.0447*	0.5352	
% Bare ground	0.0447*	0.5354	
% Live canopy	0.0244*	0.4540	
% Dead canopy	0.0001*		0.0080*

Table D.14. P values and significance of season-mow*mix interaction contrasts for July 1998 ground cover and canopy data from Ellerslie and Tawayik Lake and Oster Lake, Elk Island National Park (cont'd)

	Site		
Parameter	Tawayik Lake	Oster Lake	Ellerslie
Fall unmow vs. spring unmow * mix 1 vs. 3			
% Live vegetation	0.5710	0.0281*	
% Bare ground	0.5710	0.0239*	
% Live canopy	0.0001*	0.0142*	
% Dead canopy	0.0001*		0.0806
Fall mow vs. fall unmow * mix 1 vs. 3			
% Live vegetation	0.1613	0.1034	
% Bare ground	0.1613	0.1036	
% Live canopy	0.1103	0.2201	
% Dead canopy	0.0003*		0.0041*
Fall unmow vs. spring unmow * mix 2 vs. 4			
% Live vegetation	0.5486	0.4349	
% Bare ground	0.5486	0.4352	
% Live canopy	0.1028	0.4392	
% Dead canopy	0.9641		0.2878
Fall mow vs. fall unmow * mix 2 vs. 4			
% Live vegetation	0.7875	1.0000	
% Bare ground	0.7875	1.0000	
% Live canopy	0.5840	0.6982	
% Dead canopy	0.4140		0.2735

* indicates value significant at $\alpha=0.05$

Table D.15. P values and significance of season-mow for July 1998 ground cover and canopy data from Ellerslie andTawayik Lake and Oster Lake, Elk Island National Park

Parameter	Tawayik Lake	Oster Lake	Ellerslie
% Live vegetation	0.6686***	0.0804***	0.2196
% Bare ground	0.6286***	0.0863***	0.0907
% Live canopy	0.1826***	0.0140**	0.0002*
% Dead canopy	0.5415***	0.7325	0.0062**

* indicates value significant at α=0.05
** indicates value significant at a=0.05, affected by season-mow*mix interaction
*** indicates value affected by season-mow*mix interaction

Table D.16. P values and significance of season-mow contrasts for July 1998 ground cover and canopy data from Ellerslie and Tawayik Lake and Oster Lake, Elk Island National Park

Parameter	Tawayik Lake	Oster Lake	Ellerslie
Fall unmow vs.spring unmow			
% Live vegetation			
% Bare ground			
% Live canopy		0.0001**	0.0001*
% Dead canopy			
Fall unmow vs.fall mow			
% Live vegetation			
% Bare ground			
% Live canopy		0.4462***	0.1514
% Dead canopy			

* indicates value significant at α=0.05
** indicates value significant at a=0.05, affected by season-mow*mix interaction
*** indicates value affected by season-mow*mix interaction

Table D.17. P values and significance of mix for July 1998 ground cover and canopy data from Ellerslie and Tawayik Lake and Oster Lake, Elk Island National Park

Parameter	Tawayik Lake	Oster Lake	Ellerslie
% Live vegetation	0.0040**	0.3094***	0.0251*
% Bare ground	0.0040**	0.2903***	0.0181*
% Live canopy	0.0010**	0.2198***	0.0267*
% Dead canopy	0.0001**	0.2594	0.0609***

* indicates value significant at $\alpha=0.05$

** indicates value significant at $\alpha=0.05$, affected by season-mow*mix interaction

*** indicates value affected by season-mow*mix interaction

Table D.18. P values and significance of mix contrasts for July 1998 ground cover and canopy data from Ellerslie and Tawayik Lake and Oster Lake, Elk Island National Park

Parameter	Tawayik Lake	Oster Lake	Ellerslie
Mix 1,2 vs. 3,4			
% Live vegetation	0.0493**		0.1491
% Bare ground	0.0493**		0.7881
% Live canopy	0.3039***		0.1037
% Dead canopy	0.0006**		
Mix 1 vs. 2			
% Live vegetation	0.3804***		0.4900
% Bare ground	0.3804***		0.0384*
% Live canopy	0.6690***		0.3560
% Dead canopy	0.8892***		
Mix 3 vs. 4			
% Live vegetation	0.0029**		0.0091*
% Bare ground	0.0029**		0.0166*
% Live canopy	0.0001**		0.1385
% Dead canopy	0.0005**		
Mix 1 vs. 3			
% Live vegetation	0.0145**		0.0077*
% Bare ground	0.0145**		0.0155*
% Live canopy	0.0132**		0.4010
% Dead canopy	0.0001**		
Mix 2 vs. 4			
% Live vegetation	0.7436***		0.0251*
% Bare ground	0.7436***		0.0181*
% Live canopy	0.2961***		0.1433
% Dead canopy	0.4439***		

* indicates value significant at $\alpha=0.05$

** indicates value significant at $\alpha=0.05$, affected by season-mow*mix interaction

*** indicates value affected by season-mow*mix interaction

Table D.19. P values and significance of season*mow*mix interactions for May 1999 data from Ellerslie and Tawayik Lake and Oster Lake, Elk Island National Park

	Density (plants m^{-2})			% Biovolume			Density-Biovolume		
Parameter	Tawayik Lake	Oster Lake	Ellerslie	Tawayik Lake	Oster Lake	Ellerslie	Tawayik Lake	Oster Lake	Ellerslie
Total seeded	0.5816	0.0822	0.3793	0.4195	0.7780	0.6302	0.5687	0.1391	0.4111
Seeded grasses	0.6740	0.4739	0.3982	0.4274	0.5291	0.5380	0.5714	0.3163	0.3700
Seeded forbs	0.7471	0.2007	0.2979	0.7567	0.2857	0.5502	0.2442	0.2625	0.4046
Total non-seeded	0.9574	0.3865	0.4374	0.4195	0.7780	0.6302	0.3516	0.4969	0.6104
Non-seeded grasses	0.4433	0.9198	0.0488*	0.1015	0.9472	0.6206	0.4408	0.8747	0.4399
Non-seeded forbs	0.9708	0.3605	0.3945	0.5536	0.7274	0.7942	0.3083	0.1230	0.5123
Total all	0.9476	0.3598	0.4372						

* indicates value significant at $\alpha=0.05$

Table D.20. P values and significance of season*mow interactions for May 1999 data from Ellerslie and Tawayik Lake and Oster Lake, Elk Island National Park

	Density (plants m^{-2})			% Biovolume			Density-Biovolume		
Parameter	Tawayik Lake	Oster Lake	Ellerslie	Tawayik Lake	Oster Lake	Ellerslie	Tawayik Lake	Oster Lake	Ellerslie
Total seeded	0.0540	0.7982	0.3155	0.3628	0.1490	0.5005	0.2455	0.6175	0.8422
Seeded grasses	0.1083	0.0972	1.0000	0.1484	0.5630	0.7973	0.2913	0.2852	0.9713
Seeded forbs	0.7603	0.2318	0.0207*	0.3321	0.2694	0.1936	0.3245	0.2455	0.0689
Total non-seeded	0.8796	0.7595	0.1244	0.3628	0.1490	0.5005	0.0213*	0.7608	0.1915
Non-seeded grasses	0.2701	0.0883	0.6039**	0.8174	0.2335	0.8658	0.0709	0.9391	0.7190
Non-seeded forbs	0.8066	0.8038	0.1584	0.5571	0.2915	0.4672	0.0226*	0.7481	0.2072
Total all	0.9878	0.7865	0.1147						

* indicates value significant at $\alpha=0.05$

** indicates value significant at $\alpha=0.05$, affected by season*mow*mix interaction

*** indicates value affected by season*mow*mix interaction

Table D.21. P values and significance of season*mix interactions for May 1999 data from Ellerslie and Tawayik Lake and Oster Lake, Elk Island National Park

	Density (plants m^{-2})			% Biovolume			Density-Biovolume		
Parameter	Tawayik Lake	Oster Lake	Ellerslie	Tawayik Lake	Oster Lake	Ellerslie	Tawayik Lake	Oster Lake	Ellerslie
Total seeded	0.9517	0.0510	0.1452	0.0158*	0.5437	0.2121	0.5339	0.2994	0.2775
Seeded grasses	0.8458	0.0677	0.1042	0.0235*	0.0515	0.4328	0.6170	0.1367	0.2420
Seeded forbs	0.6815	0.0034*	0.3907	0.1575	0.0043*	0.4536	0.2281	0.0236*	0.0249*
Total non-seeded	0.3731	0.8374	0.0028*	0.0158*	0.5437	0.2121	0.0117*	0.1143	0.1266
Non-seeded grasses	0.0288*	0.0696	0.0797***	0.5358	0.1632	0.0073*	0.6382	0.0871	0.1141
Non-seeded forbs	0.0550	0.8170	0.0007*	0.0214*	0.7477	0.0258*	0.0119*	0.1230	0.1523
Total all	0.3617	0.3598	0.0018*						

* indicates value significant at $\alpha=0.05$

** indicates value significant at $\alpha=0.05$, affected by season*mow*mix interaction

*** indicates value affected by season*mow*mix interaction

Table D.22. P values and significance of mow*mix interactions for May 1999 data from Ellerslie and Tawayik Lake and Oster Lake, Elk Island National Park

	Density (plants m^{-2})			% Biovolume			Density-Biovolume		
Parameter	Tawayik Lake	Oster Lake	Ellerslie	Tawayik Lake	Oster Lake	Ellerslie	Tawayik Lake	Oster Lake	Ellerslie
Total seeded	0.7824	0.0582	0.1579	0.7088	0.0550	0.7639	0.4512	0.0003*	0.5051
Seeded grasses	0.8945	0.0232*	0.1895	0.8173	0.2495	0.6125	0.5220	0.0023*	0.5942
Seeded forbs	0.6124	0.5037	0.8090	0.1891	0.5703	0.2896	0.3165	0.4210	0.6272
Total non-seeded	0.0349*	0.9815	0.3074	0.7088	0.0550	0.7639	0.7646	0.7377	0.3477
Non-seeded grasses	0.1464	0.8583	0.4736***	0.1899	0.9155	0.3753	0.1568	0.6370	0.1796
Non-seeded forbs	0.0099*	0.9806	0.5439	0.5579	0.0458*	0.6213	0.7262	0.7431	0.5409
Total all	0.0325*	0.9848	0.3674						

* indicates value significant at $\alpha=0.05$

** indicates value significant at $\alpha=0.05$, affected by season*mow*mix interaction

*** indicates value affected by season*mow*mix interaction

Table D.23. P values and significance of season for May 1999 data from Ellerslie and Tawayik Lake and Oster Lake, Elk Island National Park

	Density (plants m^{-2})			% Biovolume			Density-Biovolume		
Parameter	Tawayik Lake	Oster Lake	Ellerslie	Tawayik Lake	Oster Lake	Ellerslie	Tawayik Lake	Oster Lake	Ellerslie
Total seeded	0.1473	0.2578	0.8503	0.1124^{SX}	0.0631	0.8371	0.2539	0.0849	0.7050
Seeded grasses	0.1420	0.3910	0.8101	0.1152^{SX}	0.0554	0.8862	0.2582	0.1827	0.7264
Seeded forbs	0.1799	0.9097^{SX}	0.6604^{SW}	0.1180	0.8818^{SX}	0.6853	0.3392	0.6567^{SX}	0.9036^{SX}
Total non-seeded	0.0921	0.3850	0.7046^{SX}	0.1124^{SX}	0.0631	0.8371	0.1221^{SX,SW}	0.5741	0.5622
Non-seeded grasses	0.2279^{SX}	0.1659	0.1579^{SMM}	0.3743	0.8874	0.5701^{SX}	0.0142*	0.9662	0.3685
Non-seeded forbs	0.0541	0.4105	0.3850^{SX}	0.1007^{SX}	0.1377	0.6707^{SX}	0.1179^{SX,SW}	0.5800	0.4646
Total all	0.0665	0.3755	0.7155^{SX}						

* indicates value significant at α=0.05

**^{SW} indicates value significant at a=0.05, affected by season*mow interaction

**^{SX} indicates value significant at a=0.05, affected by season*mix interaction

**^{SMM} indicates value significant at α=0.05, affected by season*mow*mix interaction

^{SW} indicates value affected by season*mow interaction

^{SX} indicates value affected by season*mix interaction

^{SMM} indicates value affected by season*mow*mix interaction

Table D.24. P values and significance of mow for May 1999 data from Ellerslie and Tawayik Lake and Oster Lake, Elk Island National Park

	Density (plants m^{-2})			% Biovolume			Density-Biovolume		
Parameter	Tawayik Lake	Oster Lake	Ellerslie	Tawayik Lake	Oster Lake	Ellersli	Tawayik Lake	Oster Lake	Ellerslie
Total seeded	0.0505	0.6919	0.1230	0.1049	0.1090	0.4421	0.2153	0.2046^{MM}	0.1581
Seeded grasses	0.0926	0.9324^{MM}	0.1239	0.1133	0.2314	0.2280	0.2400	0.1737^{MM}	0.1423
Seeded forbs	0.9507	0.4855	0.6591^{SW}	0.9540	0.6616	0.0757	0.7900	0.8421	0.1364
Total non-seeded	0.5570^{MM}	0.4222	0.0182*	0.1049	0.1090	0.4421	0.1369^{SW}	0.2705	0.7504
Non-seeded grasses	0.9181	0.1889	0.0095**^{SMM}	0.9430	0.7809	0.1049	0.1137	0.9564	0.0060*
Non-seeded forbs	0.5406^{MM}	0.4705	0.5785	0.1337	0.1573^{MM}	0.2146	0.1735^{SW}	0.2579	0.4192
Total all	0.6402^{MM}	0.4197	0.0163*						

* indicates value significant at α=0.05

**^{SW} indicates value significant at a=0.05, affected by season*mow interaction

**^{MM} indicates value significant at a=0.05, affected by mow*mix interaction

**^{SMM} indicates value significant at α=0.05, affected by season*mow*mix interaction

^{SW} indicates value affected by season*mow interaction

^{MM} indicates value affected by mow*mix interaction

^{SMM} indicates value affected by season*mow*mix interaction

Table D.25. P values and significance of mix for May 1999 data from Ellerslie and Tawayik Lake and Oster Lake, Elk Island National Park

	Density (plants m^{-2})			% Biovolume			Density-Biovolume		
Parameter	Tawayik Lake	Oster Lake	Ellerslie	Tawayik Lake	Oster Lake	Ellerslie	Tawayik Lake	Oster Lake	Ellerslie
Total seeded	0.9817	0.5583	0.0036*	0.4143^{SX}	0.7085	0.4159	0.7139	0.5669^{MM}	0.0594
Seeded grasses	0.7285	0.5598^{MM}	0.1379	0.2915^{SX}	0.0734	0.0125*	0.6862	0.0513^{MM}	0.0144*
Seeded forbs	0.1463	0.1680^{SX}	0.0001*	0.2839	0.0708^{SX}	0.0001*	0.4680	0.2753^{SX}	0.0001^{**SX}
Total non-seeded	0.3130^{MM}	0.8555	0.8888^{SX}	0.4143^{SX}	0.7085	0.4159	0.0674^{SX}	0.4209	0.1917
Non-seeded grasses	0.0906^{SX}	0.8298	0.4323^{SMM}	0.1584	0.2207	0.3790^{SX}	0.4347	0.2579	0.5912
Non-seeded forbs	0.4184^{MM}	0.8747	0.8486^{SX}	0.6544^{SX}	0.6805^{MM}	0.1778^{SX}	0.0679^{SX}	0.4299	0.1206
Total all	0.3602^{MM}	0.8967	0.7992^{SX}						

* indicates value significant at $\alpha=0.05$

$**^{SX}$ indicates value significant at a=0.05, affected by season*mix interaction

$**^{MM}$ indicates value significant at a=0.05, affected by mow*mix interaction

$**^{SMM}$ indicates value significant at $\alpha=0.05$, affected by season*mow*mix interaction

^{SX} indicates value affected by season*mix interaction

^{MM} indicates value affected by mow*mix interaction

^{SMM} indicates value affected by season*mow*mix interaction

Table D.26. P values and significance of mix contrasts for May 1999 data from Ellerslie and Tawayik Lake and Oster Lake, Elk Island National Park

	Density (plants m^{-2})			% Biovolume			Density-Biovolume		
Parameter	Tawayik Lake	Oster Lake	Ellerslie	Tawayik Lake	Oster Lake	Ellerslie	Tawayik Lake	Oster Lake	Ellerslie
Mix 1,2 vs. 3,4									
Total seeded			0.0005*						
Seeded grasses						0.0037*			0.0149*
Seeded forbs			0.0001*			0.0001*			0.0001**^{SX}
Total non-seeded									
Non-seeded grasses									
Non-seeded forbs									
Total all									
Mix 1 vs. 2									
Total seeded			0.3018						
Seeded grasses						0.1223			0.0317*
Seeded forbs			1.0000			0.9766			0.9888^{SX}
Total non-seeded									
Non-seeded grasses									
Non-seeded forbs									
Total all									

Table D.26. P values and significance of mix contrasts for May 1999 data from Ellerslie and Tawayik Lake and Oster Lake, Elk Island National Park (cont'd)

Parameter	Density (plants m^{-2}) Tawayik Lake	 Oster Lake	 Ellerslie	% Biovolume Tawayik Lake	 Oster Lake	 Ellerslie	Density-Biovolume Tawayik Lake	 Oster Lake	 Ellerslie
Mix 3 vs. 4									
Total seeded			0.5318						
Seeded grasses						0.7471			0.7833
Seeded forbs			0.9560			0.0515			0.2902^{SX}
Total non-seeded									
Non-seeded grasses									
Non-seeded forbs									
Total all									
Mix 1 vs. 3									
Total seeded			0.0979						
Seeded grasses						0.0029*			0.0035*
Seeded forbs			0.0001*			0.0001*			0.0001^{**SX}
Total non-seeded									
Non-seeded grasses									
Non-seeded forbs									
Total all									

Table D.26. P values and significance of mix contrasts for May 1999 data from Ellerslie and Tawayik Lake and Oster Lake, Elk Island National Park (cont'd)

	Density (plants m^{-2})			% Biovolume			Density-Biovolume		
Parameter	Tawayik Lake	Oster Lake	Ellerslie	Tawayik Lake	Oster Lake	Ellerslie	Tawayik Lake	Oster Lake	Ellerslie
Mix 2 vs. 4									
Total seeded			0.0010*						
Seeded grasses						0.2589			0.6702
Seeded forbs			0.0001*			0.0001*			0.0001**^{SX}
Total non-seeded									
Non-seeded grasses									
Non-seeded forbs									
Total all									

* indicates value significant at α=0.05

**^{SX} indicates value significant at a=0.05, affected by season*mix interaction

**^{MM} indicates value significant at a=0.05, affected by mow*mix interaction

**^{SMM} indicates value significant at α=0.05, affected by season*mow*mix interaction

^{SX} indicates value affected by season*mix interaction

^{MM} indicates value affected by mow*mix interaction

^{SMM} indicates value affected by season*mow*mix interaction

Table D.27. P values and significance of season*mow*mix interactions for May 1999 common grasses data from Ellerslie and Tawayik Lake and Oster Lake, Elk Island National Park

	Density (plants m^{-2})			% Biovolume			Density-Biovolume		
Species	Tawayik Lake	Oster Lake	Ellerslie	Tawayik Lake	Oster Lake	Ellerslie	Tawayik Lake	Oster Lake	Ellerslie
Agropyron dasystachyum	0.0144*	0.9102	0.7014	0.4441	0.8294	0.8823	0.2920	0.8894	0.8825
Agropyron trachycaulum	0.7841	0.4637	0.1906	0.2803	0.5745	0.7855	0.5601	0.4080	0.2513
Bouteloua gracilis			0.3932			0.3932			0.3932
Festuca hallii	0.6245	0.9758	0.9910	0.8145	0.5291	0.9924	0.6592	0.7135	0.9939
Koeleria macrantha			0.5931			0.8434			0.8833
Stipa viridula	0.8632	0.1502	0.2547	0.5058	0.7048	0.5923	0.6840	0.7048	0.6792

Blank indicates species not present at that site

* indicates value significant at a=0.05

Table D.28. P values and significance of season*mow interactions for May 1999 common grasses data from Ellerslie and Tawayik Lake and Oster Lake, Elk Island National Park

	Density (plants m^{-2})			% Biovolume			Density-Biovolume		
Species	Tawayik Lake	Oster Lake	Ellerslie	Tawayik Lake	Oster Lake	Ellerslie	Tawayik Lake	Oster Lake	Ellerslie
Agropyron dasystachyum	0.7232***	0.4655	0.1406	0.1429	0.0830	0.3974	0.5963	0.8394	0.1321
Agropyron trachycaulum	0.2288	0.2621	0.8206	0.1822	0.6559	0.7011	0.3177	0.2999	0.8679
Bouteloua gracilis			0.3559			0.3559			0.3559
Festuca hallii	0.4226	0.8310	0.7908	0.5761	0.6816	0.8019	0.5191	0.9061	0.3216
Koeleria macrantha			0.3942			0.6654			0.6559
Stipa viridula	0.0955	0.8075	0.8559	0.9538	0.9112	0.3743	0.7100	0.9112	0.5618

Blank indicates species not present at that site

* indicates value significant at a=0.05

** indicates value significant at a=0.05, affected by season*mow*mix interaction

*** indicates value affected by season*mow*mix interaction

Table D.29. P values and significance of season*mix interactions for May 1999 common grasses data from Ellerslie and Tawayik Lake and Oster Lake Elk Island National Park

	Density (plants m^{-2})			% Biovolume			Density-Biovolume		
Species	Tawayik Lake	Oster Lake	Ellerslie	Tawayik Lake	Oster Lake	Ellerslie	Tawayik Lake	Oster Lake	Ellerslie
Agropyron dasystachyum	0.0902***	0.3610	0.1183	0.0376*	0.2557	0.0278*	0.1155	0.7174	0.2321
Agropyron trachycaulum	0.7410	0.1026	0.0726	0.0004*	0.1125	0.1440	0.4977	0.1383	0.2808
Bouteloua gracilis			0.3932			0.3932			0.3932
Festuca hallii	0.0005*	0.0091*	0.2014	0.0059*	0.0266*	0.6356	0.0294*	0.0307*	0.4843
Koeleria macrantha			0.4714			0.8267			0.8763
Stipa viridula	0.3326	0.4058	0.1066	0.5087	0.2361	0.2442	0.4636	0.2361	0.2158

Blank indicates species not present at that site
* indicates value significant at a=0.05
** indicates value significant at a=0.05, affected by season*mow*mix interaction
*** indicates value affected by season*mow*mix interaction

Table D.30. P values and significance of mow*mix interactions for May 1999 common grasses data from Ellerslie and Tawayik Lake and Oster Lake, Elk Island National Park

	Density (plants m^{-2})			% Biovolume			Density-Biovolume		
Species	Tawayik Lake	Oster Lake	Ellerslie	Tawayik Lake	Oster Lake	Ellerslie	Tawayik Lake	Oster Lake	Ellerslie
Agropyron dasystachyum	0.0144**	0.8856	0.5668	0.3707	0.6864	0.9244	0.2505	0.7587	0.9040
Agropyron trachycaulum	0.8731	0.0059*	0.3802	0.6906	0.1116	0.2683	0.5302	0.0021*	0.4836
Bouteloua gracilis			0.3932			0.3932			0.3932
Festuca hallii	0.6245	0.9758	0.2266	0.8145	0.6369	0.9921	0.6592	0.8502	0.9722
Koeleria macrantha			0.2322			0.2235			0.1604
Stipa viridula	0.8632	0.1502	0.2482	0.5058	0.8158	0.1099	0.6840	0.8158	0.0882

Blank indicates species not present at that site
* indicates value significant at a=0.05
** indicates value significant at a=0.05, affected by season*mow*mix interaction
*** indicates value affected by season*mow*mix interaction

Table D.31. **P values and significance of season for May 1999 common grasses data from Ellerslie and Tawayik Lake and Oster Lake, Elk Island National Park**

	Density (plants m^{-2})			% Biovolume			Density-Biovolume		
Species	Tawayik Lake	Oster Lake	Ellerslie	Tawayik Lake	Oster Lake	Ellerslie	Tawayik Lake	Oster Lake	Ellerslie
Agropyron dasystachyum	0.1967^{SMM}	0.5000	0.0837	0.2019^{SX}	0.2445	0.3415^{SX}	0.2041	0.0844	0.1299
Agropyron trachycaulum	0.2811	0.5397	0.8553	0.1742^{SX}	0.1788	0.8549	0.2866	0.2728	0.7258
Bouteloua gracilis			0.3910			0.3910			0.3910
Festuca hallii	0.1257^{SX}	0.1695^{SX}	0.2993	0.0542^{SX}	0.3808^{SX}	0.6689	0.0957^{SX}	0.3330^{SX}	0.5909
Koeleria macrantha			0.5017			0.6638			0.7191
Stipa viridula	0.2048	0.5000	0.3667	0.0125*	0.0760	0.7181	0.0577	0.0760	0.9676

Blank indicates species not present at that site

* indicates value significant at $\alpha=0.05$

**^{SW} indicates value significant at a=0.05, affected by season*mow interaction

**^{SX} indicates value significant at a=0.05, affected by season*mix interaction

**^{SMM} indicates value significant at $\alpha=0.05$, affected by season*mow*mix interaction

^{SW} indicates value affected by season*mow interaction

^{SX} indicates value affected by season*mix interaction

^{SMM} indicates value affected by season*mow*mix interaction

Table D.32. P values and significance of mow for May 1999 common grasses data from Ellerslie and Tawayik Lake and Oster Lake, Elk Island National Park

	Density (plants m^{-2})			% Biovolume			Density-Biovolume		
Species	Tawayik Lake	Oster Lake	Ellerslie	Tawayik Lake	Oster Lake	Ellerslie	Tawayik Lake	Oster Lake	Ellerslie
Agropyron dasystachyum	0.7232^{SMM}	0.6985	0.0663	0.1889	0.2699	0.2583	0.6300	0.9304	0.1076
Agropyron trachycaulum	0.2001	0.5932^{MM}	0.1565	0.6584	0.2617	0.2757	0.2624	0.1855^{MM}	0.1731
Bouteloua gracilis			0.3559			0.3559			0.3559
Festuca hallii	0.4226	0.8310	0.2148	0.5761	0.5536	0.5631	0.5191	0.7466	0.7783
Koeleria macrantha			0.2574			0.1349			0.2033
Stipa viridula	0.0955	0.8075	1.0000	0.9358	0.9365	0.7242	0.7100	0.9365	0.4824

Blank indicates species not present at that site

* indicates value significant at α=0.05

**^{SW} indicates value significant at a=0.05, affected by season*mow interaction

**^{MM} indicates value significant at a=0.05, affected by mow*mix interaction

**^{SMM} indicates value significant at α=0.05, affected by season*mow*mix interaction

^{SW} indicates value affected by season*mow interaction

^{MM} indicates value affected by mow*mix interaction

^{SMM} indicates value affected by season*mow*mix interaction

Table D.33. P values and significance of mix for May 1999 common grasses data from Ellerslie and Tawayik Lake and Oster Lake, Elk Island National Park

	Density (plants m^{-2})			% Biovolume			Density-Biovolume		
Species	Tawayik Lake	Oster Lake	Ellerslie	Tawayik Lake	Oster Lake	Ellerslie	Tawayik Lake	Oster Lake	Ellerslie
Agropyron dasystachyum	0.0739^{SMM,MM}	0.2249	0.9318	0.0246**^{SX}	0.0459*	0.5965^{SX}	0.0843	0.0917	0.9632
Agropyron trachycaulum	0.7094	0.1412^{MM}	0.0473*	0.0469**^{SX}	0.0380*	0.0037*	0.6304	0.0259**^{MM}	0.0093*
Bouteloua gracilis			0.3932			0.3932			0.3932
Festuca hallii	0.0005**^{SX}	0.0056**^{SX}	0.0048*	0.0059**^{SX}	0.0320**^{SX}	0.0143*	0.0294**^{SX}	0.0331**^{SX}	0.0275*
Koeleria macrantha			0.2889			0.2374			0.1641
Stipa viridula	0.3326	0.1502	0.6106	0.5087	0.1244	0.1688	0.4636	0.1244	0.1804

Blank indicates species not present at that site

* indicates value significant at a=0.05

**SX indicates value significant at a=0.05, affected by season*mix interaction

**MM indicates value significant at a=0.05, affected by mow*mix interaction

**^{SMM} indicates value significant at α=0.05, affected by season*mow*mix interaction

^{SX} indicates value affected by season*mix interaction

^{MM} indicates value affected by mow*mix interaction

^{SMM} indicates value affected by season*mow*mix interaction

Table D.34. P values and significance of mix contrasts for May 1999 common grasses data from Ellerslie and Tawayik Lake and Oster Lake, Elk Island National Park

	Density (plants m^{-2})			% Biovolume			Density-Biovolume		
Parameter	Tawayik Lake	Oster Lake	Ellerslie	Tawayik Lake	Oster Lake	Ellerslie	Tawayik Lake	Oster Lake	Ellerslie
Mix 1,2 vs. 3,4									
Agropyron dasystachyum				0.1918^{SX}	0.0771				
Agropyron trachycaulum			0.1531	0.3933^{SX}	0.0101*	0.0279*		0.1174^{MM}	0.0262*
Bouteloua gracilis									
Festuca hallii	0.0485**^{SX}	0.4282^{SX}	0.8506	0.0844^{SX}	0.1859^{SX}	0.2307	0.1268^{SX}	0.2295^{SX}	0.3810
Koeleria macrantha									
Stipa viridula									
Mix 1 vs. 2									
Agropyron dasystachyum				0.0073**^{SX}	0.6552				
Agropyron trachycaulum			0.0151*	0.0074**^{SX}	0.2633	0.0031*		0.0099**^{MM}	0.0101*
Bouteloua gracilis									
Festuca hallii	0.0003**^{SX}	0.0032**^{SX}	0.0036*	0.0023**^{SX}	0.0103*^{SX}	0.0035*	0.0105**^{SX}	0.0105**^{SX}	0.0070*
Koeleria macrantha									
Stipa viridula									

Table D.34. P values and significance of mix contrasts for May 1999 common grasses data from Ellerslie and Tawayik Lake and Oster Lake, Elk Island National Park (cont'd)

	Density (plants m^{-2})			% Biovolume			Density-Biovolume		
Parameter	Tawayik Lake	Oster Lake	Ellerslie	Tawayik Lake	Oster Lake	Ellerslie	Tawayik Lake	Oster Lake	Ellerslie
Mix 3 vs. 4									
Agropyron dasystachyum				0.4593^{SX}	0.0295*				
Agropyron trachycaulum			0.9444	0.8722^{SX}	0.4404	0.9220		0.6309^{MM}	0.9424
Bouteloua gracilis									
Festuca hallii	0.3497^{SX}	0.0632^{SX}	0.0338*	0.5024^{SX}	0.4720^{SX}	0.4275	0.6752^{SX}	0.3763^{SX}	0.2897
Koeleria macrantha									
Stipa viridula									
Mix 1 vs. 3									
Agropyron dasystachyum				0.4229^{SX}	0.0108*				
Agropyron trachycaulum			0.0286*	0.0426**^{SX}	0.0455*	0.0021*		0.0309**^{MM}	0.0048*
Bouteloua gracilis									
Festuca hallii	1.0000^{SX}	1.0000^{SX}	0.7900	1.0000^{SX}	1.0000^{SX}	0.8214	1.0000^{SX}	1.0000^{SX}	0.8363
Koeleria macrantha									
Stipa viridula									

Table D.34. **P values and significance of mix contrasts for May 1999 common grasses data from Ellerslie and Tawayik Lake and Oster Lake, Elk Island National Park (cont'd)**

	Density (plants m^{-2})			% Biovolume			Density-Biovolume		
Parameter	Tawayik Lake	Oster Lake	Ellerslie	Tawayik Lake	Oster Lake	Ellerslie	Tawayik Lake	Oster Lake	Ellerslie
Mix 2 vs. 4									
Agropyron dasystachyum				0.0088**^{SX}	0.9491				
Agropyron trachycaulum			0.8615	0.4051^{SX}	0.0975	0.9824		0.9623^{MM}	0.7483
Bouteloua gracilis									
Festuca hallii	0.0056^{SX}	0.2631^{SX}	0.5944	0.0165**^{SX}	0.0622^{SX}	0.0553	0.0315**^{SX}	0.0901^{SX}	0.1488
Koeleria macrantha									
Stipa viridula									

* indicates value significant at α=0.05

**^{SX} indicates value significant at a=0.05, affected by season*mix interaction

**^{MM} indicates value significant at a=0.05, affected by mow*mix interaction

**^{SMM} indicates value significant at α=0.05, affected by season*mow*mix interaction

^{SX} indicates value affected by season*mix interaction

^{MM} indicates value affected by mow*mix interaction

^{SMM} indicates value affected by season*mow*mix interaction

Table D.35. **P values and significance of season*mow*mix interactions for May 1999 ground cover and canopy data from Ellerslie and Tawayik Lake and Oster Lake, Elk Island National Park**

Parameter	Tawayik Lake	Oster Lake	Ellerslie
% Live vegetation	0.0767	0.2785	0.9739
% Litter	0.8741	0.0345*	0.2922
% Bare ground	0.2410	0.1983	0.5593
% Moss	0.6589	0.0637	0.3312
% Live canopy	0.0237*	0.3977	0.9827
% Dead canopy	0.1598	0.8774	0.5903

* indicates value significant at $\alpha=0.05$

Table D.36. **P values and significance of season*mow interactions for May 1999 ground cover and canopy data from Ellerslie and Tawayik Lake and Oster Lake, Elk Island National Park**

Parameter	Tawayik Lake	Oster Lake	Ellerslie
% Live vegetation	0.1461	0.1248	0.2088
% Litter	0.4844	0.5296***	0.1132
% Bare ground	0.2354	0.5715	0.0996
% Moss	0.1575	0.3931	0.7161
% Live canopy	0.0781***	0.0350*	0.0714
% Dead canopy	0.1509	0.0837	0.0823

* indicates value significant at $\alpha=0.05$

** indicates value significant at $\alpha=0.05$, affected by season*mow*mix interaction

*** indicates value affected by season*mow*mix interaction

Table D.37. P values and significance of season*mix interactions for May 1999 ground cover and canopy data from Ellerslie and Tawayik Lake and Oster Lake, Elk Island National Park

Parameter	Tawayik Lake	Oster Lake	Ellerslie
% Live vegetation	0.4966	0.0080*	0.0004*
% Litter	0.0038*	0.0001**	0.0297*
% Bare ground	0.1640	0.0001*	0.4046
% Moss	0.0562	0.0299*	0.0118*
% Live canopy	0.0001**	0.7524	0.0036*
% Dead canopy	0.0001*	0.0725	0.1815

* indicates value significant at $\alpha=0.05$

** indicates value significant at $\alpha=0.05$, affected by season*mow*mix interaction

*** indicates value affected by season*mow*mix interaction

Table D.38. P values and significance of mow*mix interactions for May 1999 ground cover and canopy data from Ellerslie and Tawayik Lake and Oster Lake, Elk Island National Park

Parameter	Tawayik Lake	Oster Lake	Ellerslie
% Live vegetation	0.4353	0.4862	0.8873
% Litter	0.0099*	0.8356***	0.6492
% Bare ground	0.1614	0.6748	0.9209
% Moss	0.5218	0.0556	0.2747
% Live canopy	0.0466**	0.2677	0.0928
% Dead canopy	0.0604	0.2736	0.1319

* indicates value significant at $\alpha=0.05$

** indicates value significant at $\alpha=0.05$, affected by season*mow*mix interaction

*** indicates value affected by season*mow*mix interaction

Table D.39. P values and significance of season for May 1999 ground cover and canopy data from Ellerslie and Tawayik Lake and Oster Lake, Elk Island National Park

Parameter	Tawayik Lake	Oster Lake	Ellerslie
% Live vegetation	0.2553	0.1495^{SX}	0.0895^{SX}
% Litter	0.3780^{SX}	$0.3282^{SMM,SX}$	0.0790^{SX}
% Bare ground	0.1679	0.4177^{SX}	0.0659
% Moss	0.3275	0.4001^{SX}	0.0004**^{SX}
% Live canopy	$0.0674^{SMM,SX}$	0.5418^{SW}	0.5806^{SX}
% Dead canopy	0.1876^{SX}	0.2314	0.0867

* indicates value significant at α=0.05

**^{SW} indicates value significant at a=0.05, affected by season*mow interaction

**^{SX} indicates value significant at a=0.05, affected by season*mix interaction

**^{SMM} indicates value significant at α=0.05, affected by season*mow*mix interaction

^{SW} indicates value affected by season*mow interaction

^{SX} indicates value affected by season*mix interaction

^{SMM} indicates value affected by season*mow*mix interaction

Table D.40. P values and significance of mow for May 1999 ground cover and canopy data from Ellerslie and Tawayik Lake and Oster Lake, Elk Island National Park

Parameter	Tawayik Lake	Oster Lake	Ellerslie
% Live vegetation	0.2244	0.2937	0.5428
% Litter	0.0362**^{MM}	0.2266^{SMM}	0.4556
% Bare ground	0.2863	0.3882	0.4556
% Moss	0.3984	0.3458	0.7161
% Live canopy	0.0173**^{SMM,}	0.0394**^{SW}	0.0053*
% Dead canopy	0.0110*	0.0454*	0.0242*

* indicates value significant at α=0.05

**^{SW} indicates value significant at a=0.05, affected by season*mow interaction

**^{MM} indicates value significant at a=0.05, affected by mow*mix interaction

**^{SMM} indicates value significant at α=0.05, affected by season*mow*mix interaction

^{SW} indicates value affected by season*mow interaction

^{MM} indicates value affected by mow*mix interaction

^{SMM} indicates value affected by season*mow*mix interaction

Table D.41. P values and significance of mix for May 1999 ground cover and canopy data from Ellerslie and Tawayik Lake and Oster Lake, Elk Island National Park

Parameter	Tawayik Lake	Oster Lake	Ellerslie
% Live vegetation	0.0020*	0.0038**^{SX}	0.0031**^{SX}
% Litter	0.0758^{SX,MM}	0.0001**^{SMM,SX}	0.1677^{SX}
% Bare ground	0.2763	0.0001**^{SX}	0.0472*
% Moss	0.2749	0.2540^{SX}	0.0050**^{SX}
% Live canopy	0.5847^{SMM,SX,MM}	0.1376	0.3233^{SX}
% Dead canopy	0.1440^{SX}	0.5515	0.0536

* indicates value significant at α=0.05

**^{SX} indicates value significant at a=0.05, affected by season*mix interaction

**^{MM} indicates value significant at a=0.05, affected by mow*mix interaction

**^{SMM} indicates value significant at α=0.05, affected by season*mow*mix interaction

^{SX} indicates value affected by season*mix interaction

^{MM} indicates value affected by mow*mix interaction

^{SMM} indicates value affected by season*mow*mix interaction

Table D.42. P values and significance of mix contrasts for May 1999 ground cover and canopy data from Ellerslie and Tawayik Lake and Oster Lake, Elk Island National Park

Parameter	Tawayik Lake	Oster Lake	Ellerslie
Mix 1,2 vs. 3,4			
% Live vegetation	0.3424	0.0099**^{SX}	0.0584^{SX}
% Litter		0.5683^{SMM,SX}	
% Bare ground		0.2278^{SX}	0.1453
% Moss			0.2565^{SX}
% Live canopy			
% Dead canopy			
Mix 1 vs. 2			
% Live vegetation	0.0124*	0.1889^{SX}	0.0260**^{SX}
% Litter		0.0432**^{SMM,SX}	
% Bare ground		0.0251**^{SX}	0.0341*
% Moss			0.0351**^{SX}
% Live canopy			
% Dead canopy			
Mix 3 vs. 4			
% Live vegetation	0.0047*	0.3473^{SX}	0.0194**^{SX}
% Litter		0.0001**^{SMM,SX}	
% Bare ground		0.0001**^{SX}	0.2422
% Moss			0.0072**^{SX}
% Live canopy			
% Dead canopy			
Mix 1 vs. 3			
% Live vegetation	0.0010*	0.0006**^{SX}	0.1990^{SX}
% Litter		0.0956^{SMM,SX}	
% Bare ground		0.8802^{SX}	0.0077*
% Moss			0.1090^{SX}
% Live canopy			
% Dead canopy			

Table D.42. P values and significance of mix contrasts for May 1999 ground cover and canopy data from Ellerslie and Tawayik Lake and Oster Lake, Elk Island National Park (cont'd)

	Density (plants m^{-2})		
Parameter	Tawayik Lake	Oster Lake	Ellerslie
Mix 2 vs. 4			
% Live vegetation	0.0444*	0.2107^{SX}	0.1627^{SX}
% Litter		0.3863^{SMM,SX}	
% Bare ground		0.0644^{SX}	0.5371
% Moss			0.0014**^{SX}
% Live canopy			
% Dead canopy			

* indicates value significant at $\alpha=0.05$

**^{SX} indicates value significant at a=0.05, affected by season*mix interaction

**^{MM} indicates value significant at a=0.05, affected by mow*mix interaction

**^{SMM} indicates value significant at $\alpha=0.05$, affected by season*mow*mix interaction

^{SX} indicates value affected by season*mix interaction

^{MM} indicates value affected by mow*mix interaction

^{SMM} indicates value affected by season*mow*mix interaction

Table D.43. **P values and significance of season*mow*mix interactions for July 1999 data from Ellerslie and Tawayik Lake and Oster Lake, Elk Island National Park**

	Density (plants m^{-2})			% Biovolume			Density-Biovolume		
Parameter	Tawayik Lake	Oster Lake	Ellerslie	Tawayik Lake	Oster Lake	Ellerslie	Tawayik Lake	Oster Lake	Ellerslie
Total seeded	0.0515	0.3324	0.4820	0.5845	0.8048	0.0763	0.1607	0.4891	0.1202
Seeded grasses	0.1242	0.0295*	0.7278	0.5701	0.7784	0.2694	0.1652	0.1282	0.1157
Seeded forbs	0.0229*	0.4276	0.0416*	0.8463	0.6676	0.3020	0.7619	0.7338	0.4799
Total non-seeded	0.9537	0.3236	0.8624	0.5845	0.8048	0.0763	0.4766	0.4360	0.5973
Non-seeded grasses	0.7234	0.1694	0.4797	0.4427	0.4759	0.0950	0.9525	0.4224	0.5848
Non-seeded forbs	0.9711	0.2981	0.9044	0.7635	0.9406	0.1138	0.4862	0.4050	0.5756
Total all	0.9340	0.5154	0.8796						

* indicates value significant at α=0.05

Table D.44. **P values and significance of season*mow interactions for July 1999 data from Ellerslie and Tawayik Lake and Oster Lake, Elk Island National Park**

	Density (plants m^{-2})			% Biovolume			Density-Biovolume		
Parameter	Tawayik Lake	Oster Lake	Ellerslie	Tawayik Lake	Oster Lake	Ellerslie	Tawayik Lake	Oster Lake	Ellerslie
Total seeded	0.6164	0.1905	0.6717	0.9085	0.1177	0.6825	0.3357	0.2445	0.8264
Seeded grasses	0.4818	0.1867***	0.5404	0.8677	0.1535	0.5585	0.3281	0.2013	0.8133
Seeded forbs	0.8563***	0.5514	1.0000***	0.7170	0.3759	0.6179	0.6496	0.5483	0.0170*
Total non-seeded	0.1946	0.0098*	0.4148	0.9085	0.1177	0.6825	0.1697	0.1800	0.5115
Non-seeded grasses	0.5425	0.9708	0.2640	0.6400	0.0531	0.8811	0.1377	0.1204	0.9938
Non-seeded forbs	0.2220	0.0143*	0.5611	0.8260	0.2405	0.6827	0.1720	0.2100	0.5428
Total all	0.0382*	0.0311*	0.4230						

* indicates value significant at α=0.05

** indicates value significant at α=0.05, affected by season*mow*mix interaction

*** indicates value affected by season*mow*mix interaction

Table D.45. P values and significance of season*mix interactions for July 1999 data from Ellerslie and Tawayik Lake and Oster Lake, Elk Island National Park

	Density (plants m^{-2})			% Biovolume			Density-Biovolume		
Parameter	Tawayik Lake	Oster Lake	Ellerslie	Tawayik Lake	Oster Lake	Ellerslie	Tawayik Lake	Oster Lake	Ellerslie
Total seeded	0.0126*	0.8768	0.0723	0.3713	0.7436	0.1764	0.3283	0.4840	0.0101*
Seeded grasses	0.0111*	0.3393***	0.4942	0.4054	0.2842	0.4925	0.3546	0.2511	0.0223*
Seeded forbs	0.1910***	0.1461	0.1701***	0.5193	0.4665	0.9650	0.5402	0.2914	0.2147
Total non-seeded	0.2459	0.6679	0.0046*	0.3713	0.7436	0.1764	0.0003*	0.1742	0.0838
Non-seeded grasses	0.0001*	0.0016*	0.0803	0.1905	0.7920	0.9748	0.5053	0.7901	0.5143
Non-seeded forbs	0.7184	0.4829	0.0098*	0.2108	0.8073	0.1572	0.0001*	0.1636	0.1120
Total all	0.1046	0.6581	0.0031*						

* indicates value significant at α=0.05

** indicates value significant at α=0.05, affected by season*mow*mix interaction

*** indicates value affected by season*mow*mix interaction

Table D.46. P values and significance of mow*mix interactions for July 1999 data from Ellerslie and Tawayik Lake and Oster Lake, Elk Island National Park

	Density (plants m^{-2})			% Biovolume			Density-Biovolume		
Parameter	Tawayik Lake	Oster Lake	Ellerslie	Tawayik Lake	Oster Lake	Ellerslie	Tawayik Lake	Oster Lake	Ellerslie
Total seeded	0.0195*	0.4325	0.0488*	0.6839	0.0696	0.7865	0.3477	0.0273*	0.4112
Seeded grasses	0.0745	0.0103**	0.8968	0.8029	0.1150	0.6801	0.3171	0.0145*	0.4506
Seeded forbs	0.0342**	0.6403	0.0105**	0.4033	0.9451	0.4000	0.2084	0.3080	0.2703
Total non-seeded	0.3503	0.3192	0.7226	0.6839	0.0696	0.7865	0.1683	0.1658	0.8805
Non-seeded grasses	0.7527	0.2126	0.3900	0.8413	0.6894	0.1759	0.9181	0.6818	0.7926
Non-seeded forbs	0.2121	0.4170	0.7710	0.7736	0.0474*	0.7753	0.1602	0.1739	0.8953
Total all	0.4194	0.4446	0.7814						

* indicates value significant at α=0.05

** indicates value significant at α=0.05, affected by season*mow*mix interaction

*** indicates value affected by season*mow*mix interaction

Table D.47. P values and significance of season for July 1999 data from Ellerslie and Tawayik Lake and Oster Lake, Elk Island National Park

	Density (plants m^{-2})			% Biovolume			Density-Biovolume		
Parameter	Tawayik Lake	Oster Lake	Ellerslie	Tawayik Lake	Oster Lake	Ellerslie	Tawayik Lake	Oster Lake	Ellerslie
Total seeded	0.0928^{SX}	0.0651	0.5391	0.2110	0.4236	0.4183	0.2335	0.3988	0.2685^{SX}
Seeded grasses	0.1244^{SX}	0.1638^{SMM}	0.0324*	0.2140	0.5240	0.4919	0.2300	0.2867	0.2411^{SX}
Seeded forbs	0.1018^{SMM}	0.8949	0.3432^{SMM}	0.0001*	0.5573	0.8746	0.6337	0.3952	0.2649^{SW}
Total non-seeded	0.7002	0.4827^{SW}	0.6840^{SX}	0.2110	0.4236	0.4183	0.1671^{SX}	0.0430*	0.3822
Non-seeded grasses	0.0264**^{SX}	0.7422^{SX}	0.3447	0.0720	0.7048	0.8161	0.0149*	0.4447	0.6711
Non-seeded forbs	0.4028	0.4400^{SW}	0.4508^{SX}	0.2069	0.3496	0.4274	0.1595^{SX}	0.0920	0.4116
Total all	0.9681^{SW}	0.3920^{SW}	0.7096^{SX}						

* indicates value significant at α=0.05

**^{SW} indicates value significant at a=0.05, affected by season*mow interaction

**^{SX} indicates value significant at a=0.05, affected by season*mix interaction

**^{SMM} indicates value significant at α=0.05, affected by season*mow*mix interaction

^{SW} indicates value affected by season*mow interaction

^{SX} indicates value affected by season*mix interaction

^{SMM} indicates value affected by season*mow*mix interaction

Table D.48. P values and significance of mow for July 1999 data from Ellerslie and Tawayik Lake and Oster Lake, Elk Island National Park

	Density (plants m^{-2})			% Biovolume			Density-Biovolume		
Parameter	Tawayik Lake	Oster Lake	Ellerslie	Tawayik Lake	Oster Lake	Ellerslie	Tawayik Lake	Oster Lake	Ellerslie
Total seeded	0.5189^{MM}	0.3837	0.6717^{MM}	0.8545	0.4171	0.5471	0.3732	0.6470^{MM}	0.8987
Seeded grasses	0.4237	0.3182^{SMM,MM}	0.0636	0.7572	0.3854	0.6707	0.3423	0.2914^{MM}	0.7672
Seeded forbs	0.9132^{SMM,MM}	0.8511	0.0736^{SMM,MM}	0.9836	0.3126	0.8061	0.7332	0.1258	0.2512^{SW}
Total non-seeded	0.2830	0.2863^{SW}	0.7294	0.8545	0.4171	0.5471	0.3281	0.5535	0.2315
Non-seeded grasses	0.5425	0.3285	0.1871	0.9649	0.6061	0.5317	0.1201	0.3784	0.2592
Non-seeded forbs	0.3091	0.5490^{SW}	0.4325	0.7981	0.4305^{MM}	0.6131	0.2807	0.5404	0.4044
Total all	0.1560^{SW}	0.7127^{SW}	0.7417						

* indicates value significant at $\alpha=0.05$

**^{SW} indicates value significant at a=0.05, affected by season*mow interaction

**^{MM} indicates value significant at a=0.05, affected by mow*mix interaction

**^{SMM} indicates value significant at $\alpha=0.05$, affected by season*mow*mix interaction

^{SW} indicates value affected by season*mow interaction

^{MM} indicates value affected by mow*mix interaction

^{SMM} indicates value affected by season*mow*mix interaction

Table D.49. P values and significance of mix for July 1999 data from Ellerslie and Tawayik Lake and Oster Lake, Elk Island National Park

	Density (plants m^{-2})			% Biovolume			Density-Biovolume		
Parameter	Tawayik Lake	Oster Lake	Ellerslie	Tawayik Lake	Oster Lake	Ellerslie	Tawayik Lake	Oster Lake	Ellerslie
Total seeded	0.0127**^{SX,MM}	0.0245*	0.0001**^{MM}	0.2269	0.2606	0.7112	0.3005	0.8147^{MM}	0.1793^{SX}
Seeded grasses	0.0054**^{SX}	0.4359^{SMM,MM}	0.0948	0.3020	0.0585	0.0001*	0.3286	0.1256^{MM}	0.0051**^{SX}
Seeded forbs	0.0001**^{SMM,MM}	0.0086*	0.0001**^{SMM,MM}	0.0163*	0.0353*	0.0001*	0.0706	0.0456*	0.0001*
Total non-seeded	0.5263	0.7826	0.6795^{SX}	0.2269	0.2606	0.7112	0.0017**^{SX}	0.3457	0.7139
Non-seeded grasses	0.0134**^{SX}	0.0024**^{SX}	0.3953	0.0584	0.3153	0.0476*	0.2889	0.2698	0.0537
Non-seeded forbs	0.7149	0.7767	0.4456^{SX}	0.1826	0.1285^{MM}	0.9115	0.0015**^{SX}	0.2974	0.5020
Total all	0.3054	0.6012	0.1486^{SX}						

* indicates value significant at α=0.05

**^{SX} indicates value significant at a=0.05, affected by season*mix interaction

**^{MM} indicates value significant at a=0.05, affected by mow*mix interaction

**^{SMM} indicates value significant at α=0.05, affected by season*mow*mix interaction

^{SX} indicates value affected by season*mix interaction

^{MM} indicates value affected by mow*mix interaction

^{SMM} indicates value affected by season*mow*mix interaction

Table D.50. P values and significance of mix contrasts for July 1999 data from Ellerslie and Tawayik Lake and Oster Lake, Elk Island National Park

	Density (plants m^{-2})			% Biovolume			Density-Biovolume		
Parameter	Tawayik Lake	Oster Lake	Ellerslie	Tawayik Lake	Oster Lake	Ellerslie	Tawayik Lake	Oster Lake	Ellerslie
Mix 1,2 vs. 3,4									
Total seeded	0.4765^{SX,MM}	0.0106*	0.0001**^{MM}						
Seeded grasses	0.0793^{SX}					0.0001*			0.0026**^{SX}
Seeded forbs	0.0003**^{SMM,MM}	0.0023*	0.0001**^{SMM,MM}	0.0164*	0.0280*	0.0001*		0.1416	0.0001*
Total non-seeded							0.1064^{SX}		
Non-seeded grasses	0.3042^{SX}	0.5718^{SX}				0.4249			
Non-seeded forbs							0.0996^{SX}		
Total all									
Mix 1 vs. 2									
Total seeded	0.0014**^{SX,MM}	0.6763	0.5584^{MM}						
Seeded grasses	0.0034**^{SX}					0.4597			0.0711^{SX}
Seeded forbs	0.2260^{SMM,MM}	0.6809	0.7531^{SMM,MM}	0.4448	0.6008	0.9244		0.7448	0.8830
Total non-seeded							0.0004**^{SX}		
Non-seeded grasses	0.0027**^{SX}	0.0002**^{SX}				0.0245*			
Non-seeded forbs							0.0004**^{SX}		
Total all									

Table D.50. P values and significance of mix contrasts for July 1999 data from Ellerslie and Tawayik Lake and Oster Lake, Elk Island National Park (cont'd)

	Density (plants m^{-2})			% Biovolume			Density-Biovolume		
Parameter	Tawayik Lake	Oster Lake	Ellerslie	Tawayik Lake	Oster Lake	Ellerslie	Tawayik Lake	Oster Lake	Ellerslie
Mix 3 vs. 4									
Total seeded	0.8141^{SX,MM}	0.0964	0.5584^{MM}						
Seeded grasses	0.2750^{SX}					0.9970			0.4541^{SX}
Seeded forbs	0.0028**^{SMM,SX}	0.1330	0.0902^{SMM,MM}	0.0438*	0.0592	0.5307		0.0161*	0.2420
Total non-seeded							0.7858^{SX}		
Non-seeded grasses	0.3976^{SX}	0.5310^{SX}				0.1329			
Non-seeded forbs							0.6631^{SX}		
Total all									
Mix 1 vs. 3									
Total seeded	0.3145^{SX,MM}	0.2310	0.0001**^{MM}						
Seeded grasses	0.7584^{SX}					0.0001*			0.0078**^{SX}
Seeded forbs	0.0001**^{SMM,MM}	0.2184	0.0001**^{SMM,MM}	0.0022*	0.7219	0.0001*		0.7378	0.0001*
Total non-seeded							0.0023**^{SX}		
Non-seeded grasses	0.7110^{SX}	0.0706^{SX}				0.0149*			
Non-seeded forbs							0.0015**^{SX}		
Total all									

Table D.50. P values and significance of mix contrasts for July 1999 data from Ellerslie and Tawayik Lake and Oster Lake, Elk Island National Park (cont'd)

	Density (plants m^{-2})			% Biovolume			Density-Biovolume		
Parameter	Tawayik Lake	Oster Lake	Ellerslie	Tawayik Lake	Oster Lake	Ellerslie	Tawayik Lake	Oster Lake	Ellerslie
Mix 2 vs. 4									
Total seeded	0.0454**^{SX,MM}	0.0152*	0.0001**^{MM}						
Seeded grasses	0.0300**^{SX}					0.0001*			0.1067^{SX}
Seeded forbs	0.6274^{SMM,MM}	0.0019*	0.0001**^{SMM,MM}	0.7516	0.0061*	0.0001*		0.0165*	0.0001*
Total non-seeded							0.4207^{SX}		
Non-seeded grasses	0.0694^{SX}	0.0097**^{SX}				0.1884			
Non-seeded forbs							0.3740^{SX}		
Total all									

* indicates value significant at α=0.05

**^{SX} indicates value significant at a=0.05, affected by season*mix interaction

**^{MM} indicates value significant at a=0.05, affected by mow*mix interaction

**^{SMM} indicates value significant at α=0.05, affected by season*mow*mix interaction

^{SX} indicates value affected by season*mix interaction

^{MM} indicates value affected by mow*mix interaction

^{SMM} indicates value affected by season*mow*mix interaction

Table D.51. P values and significance of season*mow*mix interactions for July 1999 common grasses data from Ellerslie and Tawayik Lake and Oster Lake, Elk Island National Park

	Density (plants m^{-2})			% Biovolume			Density-Biovolume		
Species	Tawayik Lake	Oster Lake	Ellerslie	Tawayik Lake	Oster Lake	Ellerslie	Tawayik Lake	Oster Lake	Ellerslie
Agropyron dasystachyum	0.1503	0.3412	0.7330	0.2221	0.8148	0.0269*	0.2010	0.3501	0.0874
Agropyron trachycaulum	0.3853	0.3420	0.1062	0.1972	0.8936	0.4041	0.1977	0.3842	0.1219
Bouteloua gracilis									
Festuca hallii	0.2360	0.8058	0.6282	0.8890	0.6699	0.2334	0.5863	0.6699	0.2334
Koeleria macrantha			0.2597			0.5021			0.5021
Stipa viridula	0.7518	0.7649	0.4409	0.7451	0.7904	0.8349	0.8137	0.7847	0.7600

Blank indicates species not present at that site

* indicates value significant at a=0.05

Table D.52. P values and significance of season*mow interactions for July 1999 common grasses data from Ellerslie and Tawayik Lake and Oster Lake, Elk Island National Park

	Density (plants m^{-2})			% Biovolume			Density-Biovolume		
Species	Tawayik Lake	Oster Lake	Ellerslie	Tawayik Lake	Oster Lake	Ellerslie	Tawayik Lake	Oster Lake	Ellerslie
Agropyron dasystachyum	0.6094	0.0044*	0.3003	0.8343	0.1067	0.3187***	0.8895	0.1355	0.2855
Agropyron trachycaulum	0.3828	0.6237	0.5717	0.8849	0.1909	0.2090	0.2613	0.2872	0.6652
Bouteloua gracilis									
Festuca hallii	0.0955	0.4226	0.3822	0.3953	0.4226	0.6692	0.4506	0.4226	0.6692
Koeleria macrantha			1.0000			0.5370			0.5370
Stipa viridula	0.6335	0.5315	0.6099	0.1032	0.7439	0.8686	0.5680	0.7139	0.9243

Blank indicates species not present at that site

* indicates value significant at a=0.05

** indicates value significant at a=0.05, affected by season*mow*mix interaction

*** indicates value affected by season*mow*mix interaction

Table D.53. P values and significance of season*mix interactions for July 1999 common grasses data from Ellerslie and Tawayik Lake and Oster Lake, Elk Island National Park

	Density (plants m^{-2})			% Biovolume			Density-Biovolume		
Species	Tawayik Lake	Oster Lake	Ellerslie	Tawayik Lake	Oster Lake	Ellerslie	Tawayik Lake	Oster Lake	Ellerslie
Agropyron dasystachyum	0.1101	0.2229	0.4524	0.9667	0.4673	0.1591**	0.9900	0.1314	0.3332
Agropyron trachycaulum	0.4013	0.0679	0.0016*	0.1387	0.3014	0.0052*	0.6194	0.2930	0.0042*
Bouteloua gracilis									
Festuca hallii	0.0012*	0.3124	0.0051*	0.0175*	0.4040	0.0391*	0.0362*	0.4040	0.0391*
Koeleria macrantha			0.7185			0.7147			0.7147
Stipa viridula	0.4348	0.7649	0.4409	0.4156	0.2136	0.3109	0.3580	0.2706	0.3419

Blank indicates species not present at that site
* indicates value significant at a=0.05
** indicates value significant at a=0.05, affected by season*mow*mix interaction
*** indicates value affected by season*mow*mix interaction

Table D.54. P values and significance of mow*mix interactions for July 1999 common grasses data from Ellerslie and Tawayik Lake and Oster Lake, Elk Island National Park

	Density (plants m^{-2})			% Biovolume			Density-Biovolume		
Species	Tawayik Lake	Oster Lake	Ellerslie	Tawayik Lake	Oster Lake	Ellerslie	Tawayik Lake	Oster Lake	Ellerslie
Agropyron dasystachyum	0.3210	0.0518	0.8060	0.2458	0.4620	0.9165**	0.2130	0.1414	0.9040
Agropyron trachycaulum	0.2947	0.0433*	0.8110	0.8746	0.1558	0.8449	0.2707	0.0586	0.5054
Bouteloua gracilis									
Festuca hallii	0.0619	0.8058	0.0240*	0.3763	0.6699	0.0963	0.2017	0.6699	0.0963
Koeleria macrantha			0.8795			0.8933			0.8933
Stipa viridula	0.3564	0.1894	0.1310	0.6620	0.3174	0.2747	0.7021	0.3754	0.2603

Blank indicates species not present at that site
* indicates value significant at a=0.05
** indicates value significant at a=0.05, affected by season*mow*mix interaction
*** indicates value affected by season*mow*mix interaction

Table D.55. P values and significance of season for July 1999 common grasses data from Ellerslie and Tawayik Lake and Oster Lake, Elk Island National Park

	Density (plants m^{-2})			% Biovolume			Density-Biovolume		
Species	Tawayik Lake	Oster Lake	Ellerslie	Tawayik Lake	Oster Lake	Ellerslie	Tawayik Lake	Oster Lake	Ellerslie
Agropyron dasystachyum	0.2543	0.0903^{SW}	0.7843	0.0943	0.0692	0.6929^{SMM}	0.1391	0.0412*	0.7508
Agropyron trachycaulum	0.2849	1.0000	0.2529^{SX}	0.2624	0.6696	0.3366^{SX}	0.2161	0.3933	0.2442^{SX}
Bouteloua gracilis									
Festuca hallii	0.3440^{SX}	0.2048	0.1411^{SX}	0.1602^{SX}	0.0903	0.9833^{SX}	0.2675^{SX}	0.0903	0.9833^{SX}
Koeleria macrantha			1.0000			0.7177			0.7177
Stipa viridula	0.2308	0.2422	0.1170	0.2025	0.2463	0.0471*	0.3135	0.2631	0.0498*

Blank indicates species not present at that site

* indicates value significant at α=0.05

**^{SW} indicates value significant at a=0.05, affected by season*mow interaction

**^{SX} indicates value significant at a=0.05, affected by season*mix interaction

**^{SMM} indicates value significant at α=0.05, affected by season*mow*mix interaction

^{SW} indicates value affected by season*mow interaction

^{SX} indicates value affected by season*mix interaction

^{SMM} indicates value affected by season*mow*mix interaction

Table D.56. P values and significance of mow for July 1999 common grasses data from Ellerslie and Tawayik Lake and Oster Lake, Elk Island National Park

	Density (plants m^{-2})			% Biovolume			Density-Biovolume		
Species	Tawayik Lake	Oster Lake	Ellerslie	Tawayik Lake	Oster Lake	Ellerslie	Tawayik Lake	Oster Lake	Ellerslie
Agropyron dasystachyum	0.2965	0.0082**^{SW}	0.0778	0.8750	0.2284	0.2283^{SMM}	0.8727	0.1769	0.2103
Agropyron trachycaulum	0.6349	0.2550^{MM}	0.5717	0.5138	0.4098	0.1635	0.3333	0.3875	0.9751
Bouteloua gracilis									
Festuca hallii	0.4226	0.4226	0.2070^{MM}	0.4545	0.4226	0.2296	0.1715	0.4226	0.2296
Koeleria macrantha			0.2070			0.0972			0.0972
Stipa viridula	0.6335	0.8259	0.2812	0.1503	0.7439	0.4925	0.5302	0.8103	0.5068

Blank indicates species not present at that site

* indicates value significant at α=0.05

**^{SW} indicates value significant at a=0.05, affected by season*mow interaction

**^{MM} indicates value significant at a=0.05, affected by mow*mix interaction

**^{SMM} indicates value significant at α=0.05, affected by season*mow*mix interaction

^{SW} indicates value affected by season*mow interaction

^{MM} indicates value affected by mow*mix interaction

^{SMM} indicates value affected by season*mow*mix interaction

Table D.57. P values and significance of mix for July 1999 common grasses data from Ellerslie and Tawayik Lake and Oster Lake, Elk Island National Park

	Density (plants m^{-2})			% Biovolume			Density-Biovolume		
Species	Tawayik Lake	Oster Lake	Ellerslie	Tawayik Lake	Oster Lake	Ellerslie	Tawayik Lake	Oster Lake	Ellerslie
Agropyron dasystachyum	0.2151	0.0714	0.0355*	0.9532	0.7613	0.0377**^{SMM}	0.9874	0.2254	0.1111
Agropyron trachycaulum	0.8907	0.2542^{MM}	0.0177**^{SX}	0.3861	0.0851	0.0001**^{SX}	0.7229	0.1534	0.0012**^{SX}
Bouteloua gracilis									
Festuca hallii	0.0010**^{SX}	0.3124	0.0126**^{SX}	0.0007**^{SX}	0.4040	0.1077^{SX}	0.0050**^{SX}	0.4040	0.1077^{SX}
Koeleria macrantha			0.3407			0.1555			0.1555
Stipa viridula	0.2243	0.7649	0.1616	0.3718	0.0841	0.3212	0.2761	0.0960	0.1609

Blank indicates species not present at that site

* indicates value significant at α=0.05

**^{SX} indicates value significant at a=0.05, affected by season*mix interaction

**^{MM} indicates value significant at a=0.05, affected by mow*mix interaction

**^{SMM} indicates value significant at α=0.05, affected by season*mow*mix interaction

^{SX} indicates value affected by season*mix interaction

^{MM} indicates value affected by mow*mix interaction

^{SMM} indicates value affected by season*mow*mix interaction

Table D.58. P values and significance of mix contrasts for July 1999 common grasses data from Ellerslie and Tawayik Lake and Oster Lake, Elk Island National Park

	Density (plants m^{-2})			% Biovolume			Density-Biovolume		
Parameter	Tawayik Lake	Oster Lake	Ellerslie	Tawayik Lake	Oster Lake	Ellerslie	Tawayik Lake	Oster Lake	Ellerslie
Mix 1,2 vs. 3,4									
Agropyron dasystachyum			0.0440*			0.0091**^{SMM}			
Agropyron trachycaulum			0.2699^{SX}			0.0001**^{SX}			0.0050**^{SX}
Bouteloua gracilis									
Festuca hallii	0.8112^{SX}		0.5905^{SX,MM}	0.0874^{SX}			0.1702^{SX}		
Koeleria macrantha									
Stipa viridula									
Mix 1 vs. 2									
Agropyron dasystachyum			0.0384*			0.2026^{SMM}			
Agropyron trachycaulum			0.0062**^{SX}			0.1263^{SX}			0.0191**^{SX}
Bouteloua gracilis									
Festuca hallii	0.0009**^{SX}		0.0578^{SX,MM}	0.0003**^{SX}			0.0016**^{SX}		
Koeleria macrantha									
Stipa viridula									

Table D.58. P values and significance of mix contrasts for July 1999 common grasses data from Ellerslie and Tawayik Lake and Oster Lake, Elk Island National Park (cont'd)

Parameter	Density (plants m^{-2})			% Biovolume			Density-Biovolume		
	Tawayik Lake	Oster Lake	Ellerslie	Tawayik Lake	Oster Lake	Ellerslie	Tawayik Lake	Oster Lake	Ellerslie
Mix 3 vs. 4									
Agropyron dasystachyum			0.6034			0.8711^{SMM}			
Agropyron trachycaulum			0.2329^{SX}			0.0323^{**SX}			0.0968^{SX}
Bouteloua gracilis									
Festuca hallii	0.0192^{**SX}		$0.0081^{**SX,MM}$	0.3165^{SX}			0.2956^{SX}		
Koeleria macrantha									
Stipa viridula									
Mix 1 vs. 3									
Agropyron dasystachyum			0.0279^{*}			0.2567^{SMM}			
Agropyron trachycaulum			0.1191^{SX}			0.0011^{**SX}			0.0197^{**SX}
Bouteloua gracilis									
Festuca hallii	0.7355^{SX}		$1.0000^{SX,MM}$	0.8741^{SX}			0.9106^{SX}		
Koeleria macrantha									
Stipa viridula									

Table D.58. P values and significance of mix contrasts for July 1999 common grasses data from Ellerslie and Tawayik Lake and Oster Lake, Elk Island National Park (cont'd)

Parameter	Density (plants m^{-2}) Tawayik Lake	Oster Lake	Ellerslie	% Biovolume Tawayik Lake	Oster Lake	Ellerslie	Density-Biovolume Tawayik Lake	Oster Lake	Ellerslie
Mix 2 vs. 4									
Agropyron dasystachyum			0.5162			0.0105**^{SMM}			
Agropyron trachycaulum			1.0000^{SX}			0.0001**^{SX}			0.0991^{SX}
Bouteloua gracilis									
Festuca hallii	0.4996^{SX}		0.4467^{SX,MM}	0.0105**^{SX}			0.0410**^{SX}		
Koeleria macrantha									
Stipa viridula									

* indicates value significant at α=0.05

**^{SX} indicates value significant at a=0.05, affected by season*mix interaction

**^{MM} indicates value significant at a=0.05, affected by mow*mix interaction

**^{SMM} indicates value significant at α=0.05, affected by season*mow*mix interaction

^{SX} indicates value affected by season*mix interaction

^{MM} indicates value affected by mow*mix interaction

^{SMM} indicates value affected by season*mow*mix interaction

Table D.59. P values and significance of season*mow*mix interactions for July 1999 ground cover and canopy data from Ellerslie and Tawayik Lake and Oster Lake, Elk Island National Park

Parameter	Tawayik Lake	Oster Lake	Ellerslie
% Live vegetation	0.7576	0.9971	0.4136
% Litter	0.8979	0.9146	0.1464
% Bare ground	0.5479	0.7900	0.0728
% Moss	0.4601	0.5997	0.9330
% Live canopy	0.2236	0.0017*	0.5133
% Dead canopy	0.3866	0.0462*	0.5653

* indicates value significant at α=0.05

Table D.60. P values and significance of season*mow interactions for July 1999 ground cover and canopy data from Ellerslie and Tawayik Lake and Oster Lake, Elk Island National Park

Parameter	Tawayik Lake	Oster Lake	Ellerslie
% Live vegetation	0.5114	0.1578	0.2466
% Litter	0.5915	0.5403	0.3815
% Bare ground	0.3947	0.5341	0.6722
% Moss	0.4351	0.0422*	0.3019
% Live canopy	0.6505	0.8404***	0.0124*
% Dead canopy	0.2119	0.8158***	0.0110*

* indicates value significant at α=0.05

** indicates value significant at α=0.05, affected by season*mow*mix interaction

*** indicates value affected by season*mow*mix interaction

Table D.61. P values and significance of season*mix interactions for July 1999 ground cover and canopy data from Ellerslie and Tawayik Lake and Oster Lake, Elk Island National Park

Parameter	Tawayik Lake	Oster Lake	Ellerslie
% Live vegetation	0.0001*	0.0001*	0.0027*
% Litter	0.0001*	0.0001*	0.1139
% Bare ground	0.0001*	0.0001*	0.0224*
% Moss	0.2084	0.0026*	0.0073*
% Live canopy	0.0001*	0.0228**	0.5776
% Dead canopy	0.0001*	0.2087***	0.8876

* indicates value significant at α=0.05

** indicates value significant at α=0.05, affected by season*mow*mix interaction

*** indicates value affected by season*mow*mix interaction

Table D.62. P values and significance of mow*mix interactions for July 1999 ground cover and canopy data from Ellerslie and Tawayik Lake and Oster Lake, Elk Island National Park

Parameter	Tawayik Lake	Oster Lake	Ellerslie
% Live vegetation	0.7475	0.4354	0.3564
% Litter	0.9063	0.2604	0.1925
% Bare ground	0.9130	0.1099	0.1817
% Moss	0.4601	0.2193	0.3636
% Live canopy	0.0705	0.0659***	0.5185
% Dead canopy	0.1998	0.1469***	0.2991

* indicates value significant at α=0.05

** indicates value significant at α=0.05, affected by season*mow*mix interaction

*** indicates value affected by season*mow*mix interaction

Table D.63. P values and significance of season for July 1999 ground cover and canopy data from Ellerslie and Tawayik Lake and Oster Lake, Elk Island National Park

Parameter	Tawayik Lake	Oster Lake	Ellerslie
% Live vegetation	0.3911^{SX}	0.2680^{SX}	0.4870^{SX}
% Litter	0.0708^{SX}	0.5007^{SX}	0.0340*
% Bare ground	0.1803^{SX}	0.4872^{SX}	0.0268**^{SX}
% Moss	0.4920	0.5773^{SW,SX}	0.0090**^{SX}
% Live canopy	0.6779^{SX}	0.2677^{SMM,SX}	0.1176^{SW}
% Dead canopy	0.6094^{SX}	0.2962^{SMM}	0.0811^{SW}

* indicates value significant at α=0.05

**^{SW} indicates value significant at a=0.05, affected by season*mow interaction

**^{SX} indicates value significant at a=0.05, affected by season*mix interaction

**^{SMM} indicates value significant at α=0.05, affected by season*mow*mix interaction

^{SW} indicates value affected by season*mow interaction

^{SX} indicates value affected by season*mix interaction

^{SMM} indicates value affected by season*mow*mix interaction

Table D.64. P values and significance of mow for July 1999 ground cover and canopy data from Ellerslie and Tawayik Lake and Oster Lake, Elk Island National Park

Parameter	Tawayik Lake	Oster Lake	Ellerslie
% Live vegetation	0.0437*	0.3677	0.0378*
% Litter	0.2398	0.4841	0.3367
% Bare ground	0.0073*	0.7509	0.0904
% Moss	0.4351	0.2211^{SW}	0.6098
% Live canopy	0.5505	0.2200^{SMM}	0.0026**^{SW}
% Dead canopy	0.0422*	0.3199^{SMM}	0.0545^{SW}

* indicates value significant at α=0.05

**^{SW} indicates value significant at a=0.05, affected by season*mow interaction

**^{MM} indicates value significant at a=0.05, affected by mow*mix interaction

**^{SMM} indicates value significant at α=0.05, affected by season*mow*mix interaction

^{SW} indicates value affected by season*mow interaction

^{MM} indicates value affected by mow*mix interaction

^{SMM} indicates value affected by season*mow*mix interaction

Table D.65. P values and significance of mix for July 1999 ground cover and canopy data from Ellerslie and Tawayik Lake and Oster Lake, Elk Island National Park

Parameter	Tawayik Lake	Oster Lake	Ellerslie
% Live vegetation	0.0037**^{SX}	0.2035^{SX}	0.4381^{SX}
% Litter	0.3766^{SX}	0.7107^{SX}	0.0822
% Bare ground	0.2079^{SX}	0.6577^{SX}	0.1123^{SX}
% Moss	0.2084	0.3111^{SX}	0.3387^{SX}
% Live canopy	0.1100^{SX}	0.0993^{SMM,SX}	0.1374
% Dead canopy	0.1165^{SX}	0.0688^{SMM}	0.1114

* indicates value significant at α=0.05

**^{SX} indicates value significant at a=0.05, affected by season*mix interaction

**^{MM} indicates value significant at a=0.05, affected by mow*mix interaction

**^{SMM} indicates value significant at α=0.05, affected by season*mow*mix interaction

^{SX} indicates value affected by season*mix interaction

^{MM} indicates value affected by mow*mix interaction

^{SMM} indicates value affected by season*mow*mix interaction

Table D.66. P values and significance of mix contrasts for July 1999 ground cover and canopy data from Ellerslie and Tawayik Lake and Oster Lake, Elk Island National Park

Parameter	Tawayik Lake	Oster Lake	Ellerslie
Mix 1,2 vs. 3,4			
% Live vegetation	0.0245**^{SX}		
% Litter			
% Bare ground			
% Moss			
% Live canopy			
% Dead canopy			
Mix 1 vs. 2			
% Live vegetation	0.1785^{SX}		
% Litter			
% Bare ground			
% Moss			
% Live canopy			
% Dead canopy			
Mix 3 vs. 4			
% Live vegetation	0.0086**^{SX}		
% Litter			
% Bare ground			
% Moss			
% Live canopy			
% Dead canopy			
Mix 1 vs. 3			
% Live vegetation	0.0251**^{SX}		
% Litter			
% Bare ground			
% Moss			
% Live canopy			
% Dead canopy			

Table D.66. P values and significance of mix contrasts for July 1999 ground cover and canopy data from Ellerslie and Tawayik Lake and Oster Lake, Elk Island National Park (cont'd)

	Density (plants m^{-2})		
Parameter	Tawayik Lake	Oster Lake	Ellerslie
Mix 2 vs. 4			
% Live vegetation	0.3427^{SX}		
% Litter			
% Bare ground			
% Moss			
% Live canopy			
% Dead canopy			

* indicates value significant at α=0.05

**^{SX} indicates value significant at a=0.05, affected by season*mix interaction

**^{MM} indicates value significant at a=0.05, affected by mow*mix interaction

**^{SMM} indicates value significant at α=0.05, affected by season*mow*mix interaction

^{SX} indicates value affected by season*mix interaction

^{MM} indicates value affected by mow*mix interaction

^{SMM} indicates value affected by season*mow*mix interaction